THE APPLICATION OF ELECTRIC MOTORS TO MACHINE TOOLS.

Abstracted from Paper presented to the Institution, Manchester Section, by L. Miller.

Rating of Motors for Various Machine Tool Drives.

THE rating of a motor employed to drive individually any machine tool depends upon the length of time occupied in cutting metal, and the ratio of this cutting time to the total time required to complete the job.

The idle time of the machine is occupied in job setting, toolsetting, setting for cut, gauging and miscellaneous delays, and provided that the machine is operating at its maximum cutting capacity, it is by reducing these that increased workshop efficiency is obtained. This matter has received considerable attention during recent years and, where repetition work is being dealt with, remarkably high efficiencies have been obtained by feeding the machine with a constant flow of work. The general engineering shop dealing with many miscellaneous products has tackled the problem by providing setting-up tables, centralised control for the machine and push-button control for the motor.

Type of Machine	Cutting Time Per Cent. of Total Time Average	Old Method	New Method	Per Cent. Saving in Time New Method
	p.c.	p.c.	p.c.	p.c.
Radial drills	27.9	20	50	60
Pillar drills	35.4	No change. Do not lend themselves to repetition work.		
Milling machines ...	49	46	77	40
Planing machines ...	30.6	36	60-80	49-61
Vertical boring mills...	35	No change.		
Duplex vertical boring mills	62	Do.		
Centre lathes ...	61	Multiple slide rests reducing cutting and total time.		
Turret lathes... ...	52	50	60	17 Pneumatic loading
Grinding machines ...	52	55	80	31 Plunge grinding and auto-sizing
Plane milling machine	57	48.4	80.6	40

The foregoing figures will show the general tendency to increase the ratio of cutting time to total time by improved methods.

The cutting time remains the same, the gain being entirely due to a reduction in the handling time.

For the moment, leaving out of consideration planing machines, which fall in a special category, it will be seen that in all the cases considered it would not be possible to equip the machines with any recognised standard short-rated motors (such as one-hour rated). Neither is it possible to work out for any general purpose machine a standard of intermittency, because the work is so general. Apart from this, the saving in first cost which could be achieved by any means of this kind is not worth the risk of breakdown and consequent loss. These remarks apply only where the output of the motor has been accurately determined. Where large margins have been added the conditions no longer apply, although the application of a short-rated motor automatically cuts down, and sometimes eliminates, the margin.

The modern motor, which depends so much on its ventilation, does not show much reduction in cost for short ratings.

Screen-Protected Squirrel Cage A.C. Motors.—If we take the price of screen-protected motors in line with B.E.S.A. No. 168 (40° C. temperature rise) as equivalent to unity, the saving in this type of motor achieved by installing short-rated motors is in the order of 5 per cent., since it will generally be impossible to instal half-hour rated motors. The saving is not worth the limitations imposed on the machine tool to improved feeding facilities and to the increased speeds that might follow on the use of modern cutting tools. In the case of some machine tools it is, however, permissible to increase the temperature rise of the continuously-rated motor to 50° C., especially where the motor size has been determined for cutting with tungsten-carbide or titanium-carbide tools.

With totally-enclosed motors the conditions are entirely different and the continuously-rated motor becomes so large and expensive in the larger sizes that its use should be avoided wherever possible. Where the conditions are such as to necessitate complete protection the totally-enclosed fan-cooled motor offers a reasonable solution. Here again the cost is considerably in excess of the ordinary protected motor.

Most machine shops are sufficiently clean to allow of the use of screen-protected motors provided that sufficient care is taken to protect the motor from cuttings, lubricant, and droppings of any kind from the machine.

It is important to note that very fine metal dust has a peculiarly penetrative effect on insulation in general, and therefore the insulation, where very fine metal dust is likely to be drawn into the motor, should have a smooth, hard finish.

It is also important that the machine operator should be protected from draughts of air ejected by the motor, otherwise he is likely to take steps to protect himself with results that might be serious to the life of the motor.

For the majority of auxiliary drives, such as slide rests on planers, cross slides, tool holders, etc., half-hour rated motors are usually sufficient. In many cases it is possible even to reduce this rating, but if much inching is to be performed in setting up it is best to adhere to the half-hour rating.

Planing Machine Drive.

The planing machine is one of the most useful machine tools and consequently a considerable amount of thought has been given both to its design and the method of driving it. It is curious, however, that in spite of this it remains in one fundamental exactly the same as it was twenty years ago. Plate-edge planers cut on both strokes, but the ordinary engineering workshop planer still cuts on one stroke, the table returning idle, with consequent loss of time and power.

There is no doubt that grave difficulties exist in designing a satisfactory general-purpose machine to cut on both strokes. The idea is old and several attempts have been made to design such a machine, but so far as the author is aware these have not been successful.

Loss of Time Due to the Return Stroke.—The planing machine, therefore, suffers from the fact that even under the best conditions with double tables, and a return speed of 400 feet per minute, so that setting up time is cut out entirely and returning time reduced to a minimum, there still remains a period, which on an average amounts to from 6 to 50 per cent. of the total time, when the machine is cutting air. This loss of time depends largely upon the cutting speed, and is the greater the higher the cutting speed. It is only slightly variable with the length of stroke, and this is due to the loss of time in accelerating and retarding the reversing masses. A saving in time can be achieved on short strokes by keeping the reversing masses as light as possible.

Stored Energy of Moving Masses.—An examination of a number of planer drives employing reversing motors, controlled either on the Ward-Leonard principle or by contactor control gear direct from the mains, shows that most of the stored energy lies in the motor armature, illustrating the importance of reducing it to a minimum. The difficulty cannot be entirely obviated by the use of mechanical reversing gear, although it is possible to make a considerable saving by this means. For instance, in the case of a planer whose table is returning at 400 ft. per minute, the cutting stroke being at 40 ft. per minute, the energy put into and taken out of the motor armature at every reversal is 1.01 times the total stored energy. If the

planer on the other hand is cutting at 200 ft. per minute the return stroke being at the same speed, the energy put into and taken out of the motor armature will be 1.25 times the total stored energy. If a mechanical reversing drive is utilised the conditions are the reverse of this. For a cutting speed of 40 ft. per minute and a return speed of 400 ft. per minute the stored energy put into the motor armature at each reversal of the planer table will be 0.99 times the total stored energy of the motor armature. For a cutting speed of 200 ft. per minute and the same return speed, the stored energy put into the motor armature will be 0.75 times the total stored energy. The saving at the slow cutting speeds is therefore negligible, but at the high cutting speed corresponding to half the return speed it amounts to 50 per cent. of the total stored energy of the motor armature. No saving can, of course, be made as far as the stored energy of the planer table itself is concerned. This has to be taken out and put back into the table at every reversal and the amount is proportional to the square of the speed at which the table is moving.

Whichever method is used to reverse the planer table it is evident that if power is to be economised the stored energy of the motor armature should be reduced to a minimum. This is usually achieved in two ways :—

(1) By keeping the motor armature small in diameter.

(2) By keeping the maximum speed of the motor as low as possible.

Efficiency of the Drive.—Efficiency in connection with the drive of a planing machine cannot be regarded purely from the point of view of electrical efficiency. The first consideration is as to what type of drive will give maximum output with the least maintenance and loss of time due to breakdown. So much depends upon the class of work to be machined and the kind of tools to be used that each case must be worked out on its merits before a decision can be arrived at. Generally it can be said that electrical efficiency has very little influence on the decision.

The actual power costs, as a percentage of the total cost of running, vary with the size of the planer and with the ratio of running time to total time on a job. Where double tables are employed and the setting-up time is reduced to a minimum the following approximate figures have been obtained, taking the price of power at 0.75d. per unit :—

4-ft. planer. Power cost 8 per cent. of total running cost, including works on-cost ;

5-ft. planer. Power cost 10 per cent. of total running cost, including works on-cost ;

8-ft. planer. Power cost 14 per cent. of total running cost, including works on-cost ;

14-ft. planer. Power cost 16 per cent. of total running cost, including works on-cost.

Where double tables are not used, owing to the increased time during which the planer is idle these percentages would be considerably reduced.

It is clear, therefore, that an increase in electrical efficiency would make but little difference in the running cost.

Requirements of the Modern Drive.

(1) The equipment must be such as to give complete control of the cutting and return speeds of the planer table. It must be possible to adjust the cutting speed to give the best results on the kind of metal being cut and with the type of cutting tool employed. The return speed should also be adjustable, so that for a heavy job difficult to fix firmly the return speed may be suitably reduced to avoid movement of the work at reversal.

(2) It must be possible to obtain accurate work, and to plane enclosed surfaces without fear of over-running and damaging the work on the machine. In the event of the power failing the arrangement must be such that the table automatically stops, and there must be no possibility of over-running so that the work or the machine is damaged.

(3) The equipment must be so arranged that complete control of the tool is obtained from push-button stations. It must be possible to " inch " the planer table to a fraction of an inch in either direction by means of a push-button. On large planers, in order to facilitate setting-up, a complete push-button station should be arranged, so that the machinist can carry it about with him. In addition, a push button should be supplied which when pressed slows down the planer table until released. This is very convenient when a hard spot is encountered of insufficient area to warrant reducing the cutting speed.

(4) When pads on a large casting are being planed, the planer table must be speeded up between the pads when the tool is cutting air. The arrangement must be such, however, that the table is slowed down again preparatory to the tool entering the work, so that it is not damaged by entering at too high a speed.

(5) On the cutting stroke the tool must enter the work slowly and speed up after entry. It must also slow down just before leaving the work. This is particularly important when using tungsten-carbide or titanium-carbide tools at high cutting speeds, in order to prevent damage to the tool and the work.

General Trend of Development in the Application of Motors to Machine Tools.

Germany has undoubtedly led the way in applying motors to machine tools in such a manner that the combination forms a neat, compact and pleasing unit without the sacrifice of accessibility. The dimensions of flange-mounted motors and built-in motors are standardised in such a manner that the machine tool draughtsman has no difficulty in applying them when making his layout of the tool.

In this country there is such a multiplicity of motor designs on the market without standardisation in essential details that considerable difficulty arises unless the machine tool manufacturer is content to work with one motor manufacturer. This has undoubtedly contributed to the lack of progress. However, energetic steps are being taken by the machine tool makers, and it cannot be said that the motor manufacturer is not anxious to co-operate with them, so that this state of affairs should very soon be altered. The standardisation of frequency has undoubtedly assisted in removing at least one obstacle.

The same remarks apply to control gear. As already pointed out, the trend of development is definitely toward centralised control, both mechanical and electrical, of all machine tools of any size, as this method has established itself as a time-saver. This means push-button or master-switch control located alongside the mechanical control levers. The contactor gear and speed-control rheostats should be built into the machine, without destroying accessibility, to form a compact and self-contained unit, occupying as little floor space as possible. Here again, owing to the multiplicity of designs, the machine tool designer has a somewhat difficult problem to decide how to arrange his design.

Individual drive of large machine tools served by cranes has become almost universal practice. It assists materially in the layout of a shop, as the machines can be put down in the most convenient position without reference to lineshafts. It also enables the machines to be easily re-arranged to suit changed conditions or a change in the flow of work.

The foregoing remarks apply equally to small machine tools, but it must be remembered that small motors have a low efficiency, and it is no use applying individual drives unless full advantage can be taken of them, and time is saved in production by their use sufficient to compensate for the extra power required, the increased cost of the machine, and, in the case of A.C. motor drives, the increased cost of the power-factor correcting apparatus that would be involved. In a large majority of cases a consideration of these factors will establish a case for the individual drive, but there will remain cases where individual drive on small

machines will not pay, owing to the conditions under which the machine is working. For instance, if it is a question of putting a new machine into a shop in which lineshafts and pulleys are already established, and there is no difficulty in arranging a convenient drive, there will be considerable difference in the first cost between the individual drive and the lineshaft drive in favour of the latter, even if the simplest form of control gear is used in the case of the individual drive. This is, of course, a very obvious point and need hardly be enlarged upon. If, however, a new shop is contemplated, and it is desired to put down a battery of machines for any particular job, the conditions are entirely different.

For instance, if we take a case where a battery of machines would be required, consisting, say, of 17 machines, each requiring 8-h.p. to drive, then if everything is taken into account the following is approximately a comparison of the costs :—

CASE 1.

	Group drive : Motor driving 17 machines	Individual drive : Motor for each machine
Capital cost of installation, including motor, wiring, belts, and millwrighting	£615	£578
Cost per machine	£36 4s.	£34
Horsepower of motor	100	8
R.P.M. of motor	965	1440
Efficiency of motor, per cent. ...	90	89

The above comparison in costs makes it perfectly clear that where a high-speed motor can be used for the individual drive the first cost is in favour of the individual drive, even where a motor of comparatively high speed is used for the group drive. In the instance taken it will also be observed that there is very little gain in the efficiency of the bigger motor. This, of course, is not always true and it is quite possible that sometimes there may be a much wider difference than the example shows.

If we take a further example, of a much larger motor for the group drive and a larger number of machines being driven, as shown in the following table—the group-drive machine running at a much slower speed than the previous one—we get a greater discrepancy in the capital cost, again in favour of the individual drive. There is a difference, however, of three per cent. in efficiency in favour of the group drive. In considering the efficiencies, it must be taken into account whether full load can be maintained on the group-drive motor. This, it will be realised, is not generally so.

CASE 2.

	Group drive: Motor driving 23 machines	Individual drive: Motor for each machine
Capital cost of installation, including motor, wiring, belts and millwrighting	£1350	£782
Cost per machine	£58 12s.	£34
Horsepower and speed of motor ...	230	8
R.P.M. of motor	375	1440
Efficiency of motor, per cent. ...	92	89

Another point, which must not be forgotten, and which is definitely in favour of individual drive, is that belt slip can be completely avoided if the motor can be mechanically coupled. In such cases it is not unfair to say that, owing to the constant-speed running of the machine, an increase in the output per machine can be safely looked for. This has been found, where comparative tests could be made, to amount to as much as five per cent. It is only fair to point out in making these comparisons that the control conditions have been kept strictly comparable in both the individual and group drives.

Where push-button or master-switch control is required on the individual-drive motor the cost would be considerably increased and, in the first example at least, would exceed the cost of the group drive. But, logically, this type of control should not be adopted unless it can justify itself in time saved, so the comparison is strictly just. Also, the comparison does not take into account the use of variable-speed motors for the individual drive. Such motors would be considerably more expensive, and again only justify their use by some gain either in the reduced cost of the machine obtained by cutting out mechanical gears or by time saved in simplified control. The second example suffers from the fact that the group-drive motor was very much too large for its average job. It was, however, taken from an actual case where the conditions of feeding the machines were such as to keep them in practically continuous operation, and where, owing to the risk of putting one motor to drive so many machines, the customer was nervous of having too small a motor. This is not an uncommon tendency, but it usually operates against the individual drive. There is also a marked tendency to regard the group drive as giving the lower operating cost, that is to say, the lower price per article. To a very large extent this is due to each motor on the individual drive having been designed to give sufficient power to enable the maximum cuts to

be taken without straining the machine. On the other hand, conditions are usually such as to enable a motor to be put in for the group drive which would not be larger than half the total connected load demands, as allowance can be made for the effect of the feeding and setting-up time. Under such conditions the horsepower of the motor for the group drive would be reduced to 70 in the first case and 100 in the second case.

The comparison would be as follows :—

CASE 1A.

	Group drive : Motor driving 17 machines	Individual drive : Motor for each machine
Capital cost of installation, including motor, wiring, belts, and millwrighting	£580	£578
Cost per machine	£34	£34
Horsepower of motor	approx. 70	8
R.P.M. of motor	965	1,440
Efficiency of motor, per cent. ...	90	89

CASE 2A.

	Group drive : Motor driving 23 machines	Individual drive : Motor for each machine
Capital cost of installation, including motor, wiring, belts, and millwrighting	£1,155	£782
Cost per machine	£50	£34
Horsepower of motor	100	8
R.P.M. of motor	365	1,440
Efficiency of motor, per cent. ...	90	89

If we examine these two last tables, which probably indicate more nearly what should be done than the first examples, it will be seen that there is a wide discrepancy in the price per machine where the speed of the group-drive motor is low. Where the speed of the group-drive motor can be high there is probably no difference in the cost for either scheme, and the author believes that this is more nearly the truth, as far as can be ascertained, provided that all the other details remain the same. The actual issue, of course, is camouflaged by the many points which have been previously dealt with, such as the difficulty of deciding on the size of motor for individual drive. Where the conditions are definitely known there should be no

difficulty in this respect if the method of working out which the author has indicated in this paper is utilised.

It has been repeatedly stated in the literature on this subject that there is a higher first cost and repair cost per horsepower as well as a poorer electrical performance and lower reliability of motors, starters, and like equipment in small sizes as compared with larger units. This, the author has no hesitation in saying, has not been found to be the truth. In considering the large number of both types of drives with which the author is acquainted, there is no doubt at all that there is very little difference in the maintenance charges. It is, however, abundantly clear that where a breakdown occurs on a group-drive motor the loss is serious as it entails the stoppage of many machines, but, the effect on the output of a breakdown on an individual motor is practically negligible.

If we take the selection of the motor into account it is clear, of course, that the group drive may have the advantage if the conditions are very variable, and an individual-drive motor has to be put in which is capable of undertaking some very heavy job which is not an average condition. In such a case it is quite conceivable that the somewhat delicate balance of the cost will be thrown over in favour of the group drive. It can generally be taken that under reasonable conditions the group-drive motor can be accurately estimated to within 10 per cent. of its correct size. Where such variable work has to be dealt with it may be necessary to put in a motor on the individual drive twice the size of that required for the average work. This, however, emphasises the importance of carefully figuring out the size of the individual-drive motor, having in view the conditions which are likely to be met with. Where this is done with reasonable care there should be no necessity for the very wide differences in the two schemes.

In addition, there is the question of the change-speed gear box or the variable-speed D.C. motor. Where a large range of cutting speeds is demanded by the product, the variable-speed D.C. motor without gear box or combined with a small gear box having few speed changes, has undoubted advantages in that the maximum output can be obtained from the tool. Such an advantage is, however, of little use to the shop producing one article, for which the speed and feed are definitely known. These are all points to be considered in designing a machine tool, and also by the purchaser of such a tool.

It is important that, as indicated, the requirements of each machine tool be carefully studied so that the characteristic of the motor driving it can be made to suit these.

Discussion.

The following is Mr. Miller's reply to the numerous points of interest raised by members and visitors in the course of the discussion on his Paper :—

MR. MILLER : Our Chairman (*Mr. Fraser*), rightly pointed out that we are in a somewhat similar position to that when high-speed steel came into use. The change now necessary in the design of machine tools in order to use the new cutting materials is, however, even greater than it was then. This stresses the importance of carrying out much more exhaustive tests on cutting tools, similar to those which were instituted by the Manchester Association of Engineers and carried out at this College. The data given in the paper can only be regarded as preliminary and generally indicative of the direction in which the results so far obtained tend to show changes in the pressure on the tool.

With regard to *Mr. Ingham's* remarks on the German application of motors to machine tools, I think the slides shown later in the paper illustrated the fact that the British machine tool-maker is rapidly overtaking the German manufacturer.

I am afraid I do not quite agree with Mr. Ingham on the possibility of vibration being set up from the motor. It is true, of course, that vibration would be set up if the motor were not dynamically balanced in a proper manner, just as it would be set up by any other rotating mechanism not so balanced.

Mr. Pentelow asked how the pressure of the tool was actually measured in the Manchester tests. This is very fully described in the Proceedings of the Manchester Association of Engineers for the year 1911, and in fact I believe there is a drawing in the paper of the (*) special dynamometer used for this purpose. The tests took place many years ago and it is, of course, obvious that considerable advance has been made since then. If tests were undertaken now it is very probable that this type of measuring device would be superseded by a recording device similar to the oscillograph.

Mr. Pentelow also raised the question of the author having stated that the electrical losses on the single-motor drive are less than with the Ward-Leonard drive, and claims the opposite to be so. I am afraid he is wrong. The Ward-Leonard drive would consist of three machines, the efficiency of which in the average drive could not possibly be more than 90 per cent. ; the overall efficiency therefore being 73 per cent. Now the only way in which we can satisfactorily prove our case is to work out the actual losses on a Ward-Leonard drive for a planer.

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* *Illustrated in "Lathe Design," Chap. I I I, Nicolson and Smith.—Editor.*

Where, for instance, the R.M.S. H.P. to drive the planer table is 42.7, the input to the motor of the motor generator set would be

$$\frac{42.7}{0.73} = 58.4 \text{ H.P.}$$

The loss over one hour would be :

$$(58.4 - 42.7) \times 3{,}600 = 56{,}600 \text{ H.P.-sec.}$$

The H.P.-sec. returned to the line per cycle, since this energy must pass through all three machines, is :

$$(60.7 \times 1.5) \text{ H.P.-sec. per cycle} \times 0.73 = 66.4.$$

The H.P.-sec. returned to the line per hour is therefore

$$66.4 \times 165 = 11{,}000$$

there being 165 cycles per hour in this particular case. Therefore the total loss per hour would be :

$$56{,}600 - 11{,}000 = 45{,}600 \text{ H.P.-sec.,}$$

which is equal to a dissipation of :

$$\frac{45{,}600}{3{,}600} \times 12.7 \text{ H.P.}$$

For a single reversing-motor drive the figures would be :

Efficiency of motor = 90 per cent.

Therefore input to motor = $\frac{43.4}{0.9} = 48.2$ H.P.

Therefore loss over 1 hour = $(48.2 - 43.4) \times 3{,}600$ H.P.-sec.
= 17,300 H.P.-sec.

The total loss per hour in resistance = $17 \times 150 = 2{,}550$ H.P.-sec.

Therefore total loss per hour = 17,300 + 2,550 H.P.-sec.
= 19,850 H.P.-sec.,

equivalent to a continuous dissipation of $\frac{19{,}850}{3{,}600} = 5.5$. H.P.,

which is less than half that for the Ward-Leonard drive.

Mr. Pentelow has, however, stressed a point which is of little importance because, as I have very clearly demonstrated, the electrical efficiency does not matter within reasonable limits so long as some definite advantage is obtained from the extra losses. This is clearly the case where the Ward-Leonard drive is used.

Mr. Tipple mentioned the fact that most of the curves the author has shown referred to high-speed steel tools and were not applicable to tungsten-carbide and titanium-carbide tools. I think, however, that the paper clearly demonstrates what is meant. The intention is merely to show how the pressures, which can be obtained by experiment, can be applied in the calculation of the power for machine tools.

He also pointed out that the characteristic which I demonstrated for removing the maximum quantity of metal at the lowest cutting speed was only applicable to high-speed steel, and could not, of course, be applied to the more modern cutting materials. This I specially stressed in the paper and I endeavoured to show how the high speeds obtainable with these special cutting materials tended to annul this characteristic of the high speed steels, and since nobody wishes to take very heavy cuts in these days this characteristic of high-speed steel, although it existed quite clearly from the curve, was of such that it could not generally be made use of. On the other hand, the modern cutting tool with its high speed and small area of cut was of more practical value.

Mr. Scamell raised the question of comparative cost of the Ward-Leonard and single-motor drive.

This is a somewhat difficult question to answer because one must take a particular example in order to get the correct ratio of the costs. Broadly speaking, it cannot be answered generally. However, as a rough estimate it can be stated that the Ward-Leonard drive costs from 1.3 times to twice that of the single-motor drive. The exact ratio of the cost depends entirely on what is demanded of the planer with regard to cutting speeds and area of cut. When, however, we come to consider first cost in applying the drive to a planer, it can generally be said that the Ward-Leonard, especially in these days of high cutting speeds, will justify its application except on old planers which are being converted and which cannot possibly be speeded up beyond certain limits.

Mr. Throlley raised the question of multiple motors to get variable speeds and to some extent replace the gear box. These come within the range of variable-speed motors mentioned in the paper. Three to four speeds can be obtained in this way, and some of the slides shown later illustrate motors having four speeds thus obtained. This is becoming quite an established practice amongst machine tool makers.

Mr. Jenman raised the question as to why I left out the friction of the machine tool. This is obviously a variable quantity and should, of course, be known by the machine tool designer. Such figures cannot, however, be inserted in a paper of this kind. He pointed out that friction can be cut down by a change-pole motor and well-designed gear box. This, of course, is quite true. The smaller the number of wheels in the gear box the more efficient it is. On the other hand, well-designed well-cut gear wheels are not very inefficient, in spite of what Mr. Jenman said, and it is more from the point of view of convenience that the multiple-pole motor is used, than to make some fractional saving in efficiency.

With regard to the question of group drive versus individual drive, the figures given do represent an actual case. I want to

point out, however, that they also represent a case where the individual motor is figured out on a proper basis ; but even if the size of the individual-drive motor were increased to 12 H.P. there would still be a case for it. With, however, some of the absurd motor ratings that are being continually applied to these machines it can quite easily be seen that the cost will be so loaded up that the group-drive motor would be the cheaper proposition. It is this overpowering of machine tools which the author has attempted to combat in making clear how the horsepower required for the cut can be readily figured out.

Mr. Liebert indicated a method which he has very largely adopted of putting a separate motor drive on each function of a machine and having this controlled from a master position in a perfectly automatic manner, the machine operating in exactly the same way as a machine driven by one motor and mechanically coupled up in its various units. This, in the opinion of the author, is very sound practice and gives a very simple machine indeed and one which can, owing to its simplicity, be arranged almost ideally for the job.

This suggestion is specially applicable to special-process machines, as it simplifies their design and construction so much that it cuts out many of the difficulties.

Mr. Turnough, in effect, said that the electrical engineer had been slow in putting forward ideas for the drive of machine tools, and pointed out that he was of opinion that there is no electrical drive on the market as effective as hydraulic control. I am inclined to think that this is not because the electrical engineers have been slow but simply because the designer of the machine tool is mechanically-minded, and has taken mechanical means to get the desired result. If he had consulted the electrical engineer he could have done the job equally well electrically as hydraulically, producing exactly the same results with an electrical drive. It simply shows the lack of co-operation which has existed between the two engineers.

Mr. Turnough also pointed out the instability of the average generator of the Ward-Leonard set working on low voltage. This difficulty is one which has existed in the past, and has principally arisen from lack of co-operation, but is not one that is insurmountable.

With regard to the conservatism that exists, this appears to be very marked and of a rather peculiar type, since these conservative people are usually willing to accept some device of foreign extraction rather than to co-operate with the British manufacturer to produce something equally good. The hydraulic control is actually a case in point.

In conclusion, the author has to thank Mr. Ingham for his gracious remarks concerning the paper, and the members of the Institution who have so patiently listened to the lecture, and also all those friends who assisted in its preparation.

ELECTROPLATING AND DEPOSITION OF METALS.

Paper presented to the Luton, Bedford and District Section by H. S. Bavister.

I PROPOSE to commence to-night in the strictly orthodox way by explaining that the subject is too vast and comprehensive to permit of adequate treatment in one short talk. The number of recipes for superior plating solutions and the numerous and weird tonics for such solutions that have been advocated at various times are very bewildering and generally of little use, and merely surround the process of electrodeposition with an air of black mystery, and induce a lack of faith that is wholly unmerited. Anyway to-night I am proposing firstly to attempt to explain simply the theory of the process—that is, how and why it works—then to describe, in illustration, the present practice of chromium plating in so far as it embodies the latest developments and technique, and then to describe briefly a few other plating processes that are of direct interest and use to the engineer.

I am assuming that this audience to-night is essentially a mechanically minded one, and as I wish to present matters as simply as possible to endeavour to show that electroplating is really a reasonable and rational process, any electroplaters here to-night must forgive me for much that will appear to them to be obvious and elementary.

Principles.

Electrochemistry is a division of physical chemistry and as its name implies deals with the relations of chemical and electrical energy, but we are primarily concerned to-night only with a narrow branch of this study in talking about electrolysis, which is the principle of electrodeposition, and this may be defined as the chemical changes effected by passing an electric current through a chemical compound which may be either in the molten state or in the form of a solution in water. Electroplating employs such conducting solutions in water where the electric current directly affects the course of chemical reactions and without any regard to heat effects generated by the passage of that current.

As a subject of scientific interest, electrolysis is quite old, although in its early days its mechanism was imperfectly understood, and the results obtained merely as a result of empirical art. Faraday's laws

14th December, 1932.

enunciated in 1833, provided a scientific basis for further research, the accumulation of which to date has given us a fairly complete theory of the process. As in many other directions the needs of the late war time production enforced the application and development of the process, and demonstrated to some degree its practical utility and reliability, and the advent of chromium plating and its incorporation with the modern mass production methods of the automobile have given the subject its present practical interest and value.

Chemical Compounds.

To appreciate any attempted explanation of electrolytic phenomena, some understanding of chemical terms is unavoidable. Initially, in our study of chemistry, our basis is what is known as the chemical elements—that is, substances which have never been decomposed or split up into simpler substances. There are some 80 odd of these—iron, copper, nickel, carbon, sulphur, oxygen, etc., are familiar examples. These elements are considered to be made up of atoms which are the smallest particles of matter that can enter into chemical reactions. Modern physics has demonstrated the complicated structure of these atoms, but for our purposes to-night such considerations merely tend to confusion and unnecessarily complicate matters so that I propose to ignore them. When an atom of each of two elements react together and combine, they form one molecule of a compound—a molecule being defined as the smallest particle that can exhibit the properties of a compound or substance. For instance, one atom of sodium combining with one atom of chlorine forms one molecule of sodium chloride, i.e., common salt.

It has been found that each kind of atom combines or reacts with other kinds of atoms always in definite proportions by weight, and thus has been evolved what is known as the system of atomic weights of the elements. As chemistry universally employs the metric system, we take as our unit, the weight of our lightest atom—that of hydrogen as one gramme. Thus we speak of the atomic weight of hydrogen as one gramme, oxygen 16 grammes, nickel 58.7 grammes, iron 55.8 grammes, copper 63.6 grammes, etc. Thus water, well known as H_2O, consists of two atoms of hydrogen equivalent to two grammes, and one atom of oxygen equivalent to 16 grammes ; thus 18 grammes of water contain two grammes of hydrogen (11.1 per cent.) and 16 grammes of oxygen (88.9 per cent.). Similarly unslaked pure lime is calcium oxide—one atom of oxygen (16 grammes) for every one atom of calcium (40 grammes). Throughout the whole universe, all chemical compounds consist of atoms always combined in these exact quantitative proportions of their atomic weights.

There is one other feature of atoms that we must consider and that is what is known as their " valence " and this is, in effect, their

combining ratio. We again take hydrogen as our basis of unit valency or combining ratio, and in considering the following formulæ of compounds : HCl, H_2O, NH_3, CH_4, we see that chlorine combines with one atom of hydrogen, oxygen with two, nitrogen with three, and carbon with four, and this ratio of combining power of the atoms in terms of the hydrogen atom is the " valence "—thus chlorine ratio is one, and it is therefore described as " monovalent " ; oxygen has ratio two and is " divalent," nitrogen three—trivalent, carbon four—tetravalent. Taking a compound like nickel chloride $NiCl_2$, we know chlorine to be monovalent, and therefore nickel is divalent, and so from the constitution of the various chemical compounds, we can determine the valence of all the elements. The importance of this knowledge is that by dividing the atomic weight of an element by its valence, we obtain what is known as the equivalent weight of that element—that is, the weight of that element that will react with, or displace, or is equivalent to, one gramme of hydrogen. Thus oxygen has equivalent weight of eight, nickel 29.4, copper 31.8 ; chromium has atomic weight of 52 and valence of six so that its equivalent weight is 8.66. Faraday first discovered the importance of this equivalent weight feature of an element in relation to electrolysis and it forms the basis of the quantitative efficiency of the process.

Having gained some knowledge of the composition of chemical compounds, we will consider their characteristics. Inorganic compounds can be divided into three classes—acids, bases, salts. Acids all contain one or more atoms of hydrogen which can be replaced by atoms of a metal. Bases can be oxides or hydroxides of the metals, and they neutralise or react with the acids to form salts.

H_2SO_4	+	NiO	=	$NiSO_4$	+	H_2O
Sulphuric Acid		Nickel oxide		Nickel Sulphate		Water
HCl	+	NaOH	=	NaCl	+	H_2O
Hydrochloric acid		Sodium hydroxide		Sodium chloride		Water

We thus see how these compounds known as salts are formed and this is important as the process of electrolysis as applied in electroplating practice concerns the effect of the electric current in decomposing or modifying the composition of these salts. A simple illustration of this is afforded by the normal nickel plating solution—pure water has negligible conductivity for an electric current, but when acids, bases or salts are dissolved in it, the resulting solutions do conduct electricity and are known as electrolytes. In such solutions, the process of dissociation or ionization has occurred to some extent—that is, some of the molecules of the dissolved com-

pounds split up into atoms or groups of atoms of two general kinds, which carry tiny charges of electricity, and are known as IONS.

Thus $NaCl \longrightarrow Na^{+} + Cl^{-}$
$NiSO_4 \longrightarrow Ni^{++} + SO_4^{--}$

The number of charges of electricity attached to each atom is the same as its valence. This " ionization " occurs when the salt is simply dissolved in the water and the solution has of course no total electric charge since there are present equal number of positive and negative charges. The ions which bear positive charges are known as cations, and those with negative charges as anions. If now two wires from an outside source of current are led separately into such a solution, the cations with their positive charges are attracted towards the negatively charged wire and the anions with their negative charges to the positive wire. The negatively charged wire is therefore known as the cathode and the positive as the anode.

Thus in a nickel plating solution considered essentially as a solution of nickel sulphate in water, at the cathode we have the cations, i.e., nickel atoms with tiny positive charges being attracted and making contact, giving up their electrical charges and becoming nickel atoms, uniting into molecules and forming a deposit of metallic nickel. At the anode, the anions—sulphions give up their charges and tend to exist in the free state. They react with the anode if it is made of nickel, dissolving it and forming nickel sulphate which enters into solution and is dissociated into its ions again.

The net result of this is that atoms of nickel in the anode pass into solution carrying positive electrical charges and, thus becoming nickel ions, pass through the solution to the cathode where the charges are given up and nickel atoms deposited. Thus the passage of electric current through the solution performs nickel deposition.

Michael Faraday, in 1833, determined the quantitative basis of electrolysis when he proved that :—

(1) The *amount* of any substance that is deposited is proportional to the *quantity* of electricity which flows through the electrolyte. (Solution).
(2) A quantity of electricity will deposit amounts of different substances which amounts are exactly proportional to their equivalent weights.

With regard to the first law, the ampere is a rate of electricity flow—and therefore a quantity of electricity is a product of amperes and time—thus a current of five amperes flowing for ten minutes is the same amount of electricity as a current of 25 amperes for two minutes, and will therefore deposit the same amount of metal at a cathode, and similarly 50 amperes for two minutes will deposit twice the weight of metal.

With regard to the second law, as the equivalent weight of cadmium is 56.2 and that of copper is 31.8, a given amount of electricity will deposit a greater weight of cadmium than of copper in the ratio of these equivalent weights—that is $\frac{56.2}{31.8}$

Developing these laws, we have the fact that 96,580 amp. seconds of electric current (or in commercial units 26.8 ampere hours) will deposit the equivalent weight of an element expressed in grammes—such as 56.2 grammes cadmium, 31.8 grammes copper, 29.3 grammes nickel, 107.9 grammes silver. From this fact, knowing the density of the metal deposited, and the area plated, we can calculate the theoretical mean thickness of a deposit resulting from the passage of a definite current for a definite time. We can thus also determine the efficiency of a plating solution ; in a nickel plating solution if we weighed our cathode areas, before and after plating with a measured amount of current, the increase of weight would give the actual weight of nickel deposited, while from the current data we could calculate the theoretical gain in weight and thus derive our percentage cathode efficiency. With a similar procedure we can determine the anode efficiency and for a normal nickel plating bath these electrode efficiencies approach very closely to 100 per cent. If the nickel solution contained a large amount of free sulphuric acid, we should find that the cathode efficiency might be as low as 70 per cent. That is, only 70 per cent. of the current would usefully deposit nickel, the remaining 30 per cent. would be merely decomposing the excessively acid solution to liberate hydrogen gas at the cathode surface.

Properties of Plating Solutions.

Obviously, from an electrical power cost point of view, the ideal plating solution should have electrode efficiencies approximating to 100 per cent. and this is also of importance in the maintenance of the composition of the solution. Any loss of electrode efficiency inevitably means that some of the current is doing some useless work and as this generally means the decomposition of some other constituent of the solution, that decomposition must be periodically made good by additions of chemical substances to the bath.

The rate at which a plating solution will work should naturally be as high as possible and this is commonly expressed and controlled in terms of " current density " : this is the rate of current flow per unit area of the cathode and generally stated in amperes per square foot, and this is controlled by the voltage between anode and cathode. The tendency of modern plating solution development is naturally towards higher current densities to give shorter plating times. For instance, the older cold nickel plating solutions made

up principally from the "double nickel salt" could rarely be operated at higher current densities than 10 amps. per square foot (generally at six amps. per square foot), whereas modern hot solutions operate at 30 amps. per square foot (and in special circumstances up to 100 amps. per square foot). Obviously, the solution with current density of 30 amps. per square foot is working three times as fast as the old bath at 10 amps. per square foot, and will therefore give the same thickness of deposit in one-third the time.

The value of the current density greatly affects the grain size of the deposited metal—a very low current density gives a coarse grained deposit—increasing the current density gives a finer grained deposit until an excessively high current density gives the familiar

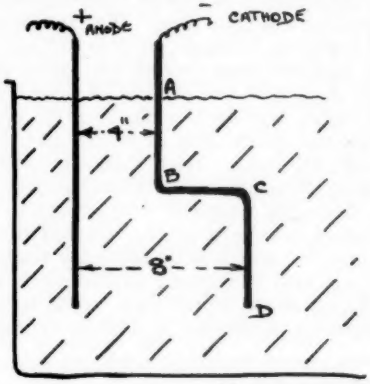

DIAGRAM 1.

"burnt" deposits. Increasing the temperature of the solution or agitating it by air or mechanically operated paddles, or by moving the cathode through the solution during plating, all permit higher current densities to be used without causing "burning" of the deposit.

Another very important property of a plating solution concerns its "throwing power"—that is the ability of the current to be "thrown" into any recesses on the cathode, and there to deposit the metal.

If we consider an irregularly shaped cathode as *ABCD* (diagram 1) with the distance from anode of *CD* being twice that of the distance *AB* from anode, as we have obviously the same voltage between all surfaces of the electrodes, the different lengths of solution and their proportional resistances between these two parts of the cathode and the anode will cause *AB* to receive, theoretically, twice the

current of *CD* and therefore twice the thickness of the deposit. Due to combination of several other detailed properties of the solution, which properties include conductivity, cathode efficiency and polarization variation with varying current densities, plating solutions vary enormously in their ability to throw into recesses and give wide variation of the above theoretical current distribution.

These published experimental data by Field in this direction are illuminating.

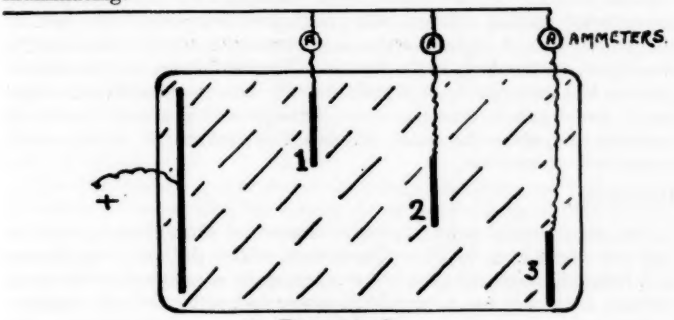

DIAGRAM 2.

Three cathodes of equal area and at equal distances from one another and the anode—if "throwing power" were perfect they would each receive one-third of the total current, but actual experiments showed :—

Plating Solution	Current Distribution		
	Cathode No.		
	1	2	3
Copper sulphate ...	58.3%	30%	11.7%
Zinc sulphate	62.5%	34.7%	2.8%
Zinc cyanide	43.4%	31.9%	24.7%

The very obvious superiority of the cyanide solution in this matter of throwing power is incidentally common to most cyanide solutions.

Plating Practice.

I now propose to defer the further consideration of the properties of solutions until they can be incidentally illustrated during the description of current production practice.

The history of the practice of plating is quite naturally linked up with the history of the generation of the electric current. In 1840, the Elkington Bros., of Birmingham, took out English patents for electroplating with silver and gold from cyanide solutions and

as their solutions were the first with which it was possible to obtain thick deposits, they were of great commercial importance but as their only source of current was from primary batteries, their amperage and therefore their output was limited. In 1844 Woolrych constructed the first machine for generating current that was used industrially for silver plating. As dynamos were developed, electroplating output was increased and silver plating for the jewellery trades was of first importance. The first patent for a nickel plating solution was granted to Adams in 1869, and as the production of nickel anodes was improved, the process rapidly developed, particularly in the States. The introduction of chromium plating has recently been responsible for the most rapid advances and I now want to describe some of its present practice since it of necessity requires the most advanced technique of many other associated operations.

Polishing.

The most useful property of a deposit of chromium is that it will not tarnish or become discoloured under ordinary conditions and hence it shows to greatest advantage as a polished or lustrous surface, and as it has a very high lustre and reflectivity it requires a very good standard of polished finish. Fine scratches that would excite no comment on a polished nickel surface become really blatant and unsightly after chromium plating. This increase in the standard of buffing required, intitially caused much consternation and expense, but as is generally the case when a standard is raised, after the first shock has been forgotten, a generally increased all-round efficiency results.

Polishing is generally by far the most costly of any of the operations necessary for the production of plated work, and although no startling inventions of new equipment or methods have resulted, the production study of the operations resulting in some measure of standardisation of wheel shapes and sizes and materials, in conjunction with the use of larger and more rigid and powerful motor-driven polishing lathes, has resulted in some very drastic reductions in polishing costs. It is partially true to say that the final plated polish is no better than that of the base metal and this phase of the polishing is of the greatest importance. Automatic polishing machines have not as yet found any large application, particularly in this country ; primarily they are costly and not suitable for any but very simple shapes. With complicated shapes, the master cam mechanism, controlling the chuck and part to be polished, becomes very elaborate and it is difficult to maintain the required smooth blending of the surface finish at edges and sudden changes of plane. Automatic polishing machines are thus only economically possible where a very large volume of simple shapes are to be handled.

For rapid output, the peripheral speed of polishing wheels should be as high as possible (5,000 to 9,000 per minute) which will mean polishing lathe spindle speeds up to 2,500 r.p.m., and with powerful lathes large ball bearings are necessary. A 16-ins. by 3½-ins. wide wheel can absorb about 3 h.p. A very cheap and generally useful wheel is the stitched white linen mop, made of pieces of cloth stitched together to form a disc, say, ½-in. thick—these discs being nailed and washered together to form the wheel of required face width. Discs are commonly ½-in. thick in this country, but in the States ⅜-in. thickness is more general; this gives a slightly more flexible wheel which is probably necessary to meet their usually higher peripheral speeds. The stitching gives stiffness, and yet the relative softness of the cloth face is retained and this wheel is for the majority of purposes preferable to felt both on the score of cost and of utility.

The first polishing operations are emery grinding, and these cloth wheels are dressed with the emery powders by means of glue. This requires considerable care and attention to detail to obtain the maximum wheel life. The glue used should be of the best quality, from hide or skin, as this stock has the greatest flexibility. To develop the maximum strength of the glue, it should be soaked adequately with its correct weighed amount of cold and pure water—ground glue needs three hours soaking—flake glue eight hours, cake glue twelve hours, minimum. A small quantity only should be melted down at a temperature that preferably does not exceed 150° F. and all used up within four hours of being melted, for it loses approximately five per cent. of its strength for every hour that it is heated, and thus glue pots and brushes should be cleaned and sterilised with weak carbolic solution every night, as old glue will reduce the strength by one-half. To prevent chilling of the glue during dressing, wheels and emery should be heated to 120° F. and to obtain the greatest strength the glue should be allowed to set for forty-eight hours at atmospheric temperature — away from draughts or high temperature.

The practices sometimes advocated of adding Russian Isinglass and glycerine to improve respectively the strength and flexibility of a glue are not necessary or advisable if a good quality glue is originally selected.

A freshly dressed emery wheel is very fierce in its cutting action and should be " broken in " by working on some rough castings or similar rough work. The preliminary grinding operations should be conducted as gently and with as fine a grit as possible, for a few seconds thus sacrificed with these wheels are more than counter-balanced by minutes saved in the later polishing stages.

For the average mild steel pressing, a very little attention with 100 grit wheel should be necessary, followed by thorough grinding

on 120 grit wheel. A following operation with 160 grit or a well worn 140 grit wheel prepares the surface for a final treatment with wheel dressed with flour emery. A further polishing operation is sometimes given—using a fibre brush to which is applied " brushing emery composition " which is essentially flour emery and other abrasive grits compounded with about 50 per cent. of solid grease base consisting of paraffin wax and stearine and sometimes some tallow. While this brushing operation is useful for polishing recesses and edges that would be difficult and probably dangerous with a cloth wheel, a brush is relatively inefficient, and I do not think that this operation is worth while. The very low carbon fully annealed or normalised sheet used for cold pressings very easily tears or drags under an emery wheel and the use of plenty of tallow grease as a lubricant is desirable. Using wheels in a suitable condition with tallow grease, the polishing operations can frequently be simplified to three only—100 grit—140 grit and flour wheels. In the States, tallow grease stick is very lavishly used for practically all polishing operations and is probably necessary in view of their very high wheel speeds around 8,000 feet per minute.

Brass is in some respects an easier metal to polish than mild steel and with tubes or pressings with the normal commercial finish, a light treatment with 120 grit wheel followed by polishing with an undressed stitched mop fed with tripoli compound will relatively quickly give a highly lustrous surface. Tripoli composition is the usual grease base compounded with tripoli which is a naturally occurring abrasive consisting essentially of hydrated silica.

Cleaning.

The first of the operations of the scheme which now follows is cleaning, and although this sounds very ordinary and commonplace, where a surface is to be finally chromium plated this operation is, I think, undoubtedly the most important and difficult of the whole procedure. The final application of a deposit of chromium is in actual practice a most severe test of the adhesion of any underlying plated deposits to the base metal, and any imperfections in this direction are readily manifested by peeling or blistering of the deposits. Where the base metal surface is highly polished, the contact of the nickel deposit must be just as intimate and absolute as possible ; we know that two pieces of steel can be made to cohere if their engaging surfaces are very flat and highly polished, and it is probable that intermolecular forces are operative. Similar conditions exist to some extent with our electrodeposits and any films of grease or oxide on the base metal surface prevent the necessary intimate contact, and faulty adhesion results.

The complete removal of all traces of grease or oil films from a metal surface under commercial conditions is difficult and the fact

that our base metal surface is more or less covered with a film of the polishing grease, which is solid and loaded with abrasive and abraded matter, complicates the problem, and a successful procedure generally involves several operations. A desirable first treatment is with trichlorethylene which is a sweet smelling liquid with boiling point 87°C., is non-inflammable and has a marvellous solvent power for oils and greases. Simply and crudely, the articles to be cleaned can be dipped in the liquid which, however, thus soon becomes contaminated with the greases, etc., which are left behind as a thin film on the surface of the work when the latter is removed from the trichlorethylene and the surface dries off. The better form of cleaning equipment therefore employs only the vapour of trichlorethylene, and consists of a galvanised tank with steam coils in the bottom where liquid trichlorethylene is being constantly boiled and converted into vapour. Cold water coils are fitted inside the top of the tank, and, condensing the vapour, prevent it escaping from the tank and return it to the bottom in the form of a fine shower of drops of the condensed *pure* liquid. Parts placed in this tank are thus constantly exposed to vapour and drops of the pure solvent, and greases are thus very efficiently removed. Exposure of an operator to large amounts of trichlorethylene vapour may cause headaches or even sickness, but with sensible operation there is little risk of this, and the procedure can be considered to be perfectly safe from this health hazard point of view.

While grease and oil can thus be effectively removed, solid particles of abrasive or abraded metal, etc., will remain upon the work, as they are entirely unaffected by the trichlorethylene, and additional cleaning procedure is therefore necessary. This should take the form of an electrocleaner, which is a tank containing a cleaning solution and operated electrolytically. These solutions consist of various alkalis dissolved in water and they are generally used at temperatures approaching the boiling point. With regard to the heating of these solutions, and in fact plating solutions in general, the use of steam coils is ideal as they admit of easy control and are rapid and economical in operation. Live steam has somewhat similar advantages and gives effective circulation of the solution which may, or may not, be an advantage, depending upon the solution in question. It has the disadvantage of spoiling the shop atmosphere unless tanks are well hooded, and as it is inevitably condensed in passing through the solution, may cause excessive dilution of the latter.

Gas heating by jets burning under a tank, of course, presupposes the tank to be made of iron and although it admits of easy control for low temperatures of solution, it is expensive and inefficient particularly for higher solution temperatures, and gives a poor shop atmosphere.

Electricity is ideally clean, but very slow in operation although it

shares with steam an ability to be easily adapted to work with thermostatic control.

Steam coils should be electrically insulated at both ends and in the case of our electrocleaner should be preferably arranged vertically at one end of the tank so that some circulation of the solution occurs, and scum and dirt collecting on the surface may thus be carried to the other end of the tank and away by means of an overflow device. The electrocleaner solutions contain primarily an alkali such as soda ash or caustic soda which will react with vegetable and animal fats to form soap and glycerine which are soluble in water. Mineral oils cannot be saponified in this way and must be removed by the process of emulsification for which purpose soap and similar compounds are added to the solution. A solution could thus contain up to eight ozs. soda ash and one oz. of caustic soda and $\frac{1}{2}$-oz. of whale oil soap per gallon water. High concentrations of caustic soda are unnecessary as they are very dangerous to the operators and are not greatly more efficient than the milder alkalis. Recent cleaning developments are to include in the solution some substance which will generate a fine powder or precipitate which, due to adsorption and scouring effects, greatly assists the removal of mineral oil—such substances are sodium silicate or water glass, sodium aluminate and trisodium phosphate. A solution of this type could consist of two ozs. soda ash and one oz. caustic soda, and two ozs. trisodium phosphate or one oz. either of sodium silicate or of sodium aluminate per gallon. It is impossible to give any one formula for a cleaning solution that will most efficiently suit all conditions, but the foregoing remarks indicate the lines upon which suitable solutions can be developed to meet particular requirements and it should be generally remembered that the stronger alkaline solutions are rarely necessary and quite frequently less efficient.

The passage of the electric current through this cleaning solution results in the evolution of much hydrogen gas at the work surface which is the cathode, and this gas discharge gives very vigorous local agitation of the solution and thus mechanically greatly assists the cleaning of the work surface. The current density necessary to achieve this vigorous gas evolution should be as high as convenient between 10 and 40 amps. sq. ft. and where the anode is formed by the steel tank itself employing a central cathode bar, the voltage across the terminals will need to be between six and 10, and as the time of operation is short and total amperage high, a separate motor generator which is preferably mains excited, is desirable. The time required for this electrocleaning operation will be between two and ten minutes, and four to five minutes is commonly ample. After a solution has been in use for some time, it may contain some tin or zinc dissolved from soldered joints and parts which have been handled, and these metals may become deposited on the work. To

meet this condition, a reversing switch should be connected in the circuit so that after the work has been normally cleaned for say four minutes, the current can be reversed for a short time, i.e., up to one minute when the work becomes the anode, and any films of tin or zinc are redissolved by the solution. Alternatively, of course, the solution can be thrown away and a new one made up, but the reversing switch is well worth fitting anyway.

Cleaning completed, the work is removed and thoroughly swilled quickly in clean cold running water and it should show by the complete absence of " water breaks " on its surface that it is quite clean. If it is not perfectly clean, hand scouring with pumice powder and bristle brush should follow. Pumice powder is perferable to lime or chalk as it is more easily completely swilled away subsequently in water.

This cleaning scheme and particularly the hand scouring operation will, no doubt, seem to be elaborate and expensive production, but experience indicates that it is cheaper to keep down final plated scrap to less than half per cent. in this way, than to eliminate the hand scouring and find scrap mounting towards three to five per cent. Most large American automatic plants do not incorporate hand cleaning but this is only because their cleaning scheme will embody either electrocleaners with very high current densities or else, or additionally, use washing machines where the hot cleaning solution, in the form of high pressure jets, impinges on the work with some real mechanical force. It is my opinion that unless a large work volume justifies the capital outlay of such special cleaning equipment, then some hand scouring is economical to assure reliable cleaning and adhesion.

Cleaning being thus completed, as far as the removal of all foreign matter is concerned, the work is passed through various " dipping " solutions which will remove any slight oxidation films or tarnish and thus render the metal surface chemically clean. A common sequence of such operations is firstly a dip in five per cent. solution of sodium cyanide followed by water swill and then dip in five to 10 per cent. sulphuric acid solution, followed by water swill. This scheme is suitable for both steel and brass but if steel parts only are handled, the acid dip may preferably be 10 to 15 per cent. hydrochloric acid solution. When handling brass parts only, the cyanide solution dip can with advantage be operated electrolytically with a reversing switch, when some etching of the brass surface will greatly enhance subsequent adhesion of the electrodeposits. Following these operations, the work should be quickly immersed in the plating solution, for it must be realised that a chemically clean brass or steel surface will, upon exposure to the air, quickly develop a surface film of oxide which is very real and effective in reducing the necessary intimacy of

contact and therefore the adhesion of the subsequently deposited metal.

Plating Operations.

The type and scope of plating operations necessary as preparatory to chromium plating can be varied to some extent, but primarily the deposit should consist of nickel of a thickness of 0.001-in. This is completely safe for brass but represents minimum requirements for steel. This can be simply and directly deposited on the base metal, but it is proved that a composite deposit of two suitable metals will give better corrosion resistance than a single metal deposit of the same total thickness. As copper is suitable and cheaper than nickel, it is sound practice first to deposit copper. Two types of copper plating solution are available—the cyanide bath and the acid copper bath, with the distinctions that the cyanide bath is slower, but has better throwing power, giving a deposit of greater denseness and hardness, but it is not suitable for thick deposits. The copper sulphate bath will give any thickness of deposit, but cannot be used as a first plating operation on a steel surface as a loose powdery form of copper is initially formed by a purely chemical reaction, so that the superimposed electrodeposit has poor adhesion. It is therefore necessary when employing this solution, first to deposit a thin film of nickel, say, 0.0002-in. thick or a film of copper from a cyanide bath. A suitable plating scheme can, therefore, be first 0.0002-in. nickel, followed by cold water swill, then 0.0004-in. to 0.0006-in. copper from sulphate bath, followed by a swill and a 0.0005-in. nickel giving a total thickness of around 0.0012-in., which will allow for polishing losses to leave the required 0.001-in. thickness necessary for corrosion resistance.

An alternative plating scheme, and a rather simpler one, is to deposit up to 0.0003-in. copper from cyanide bath followed by up to 0.0008-in. nickel. Both of these solutions have good throwing power effectively to penetrate into recesses, and the copper cyanide bath has the advantage that it is also to some extent a cleaning solution. The cathode efficiency of the solution is low, around 45 per cent., so that much of the current is used in generating hydrogen gas at the work surface, thus adding to the cleaning properties which are possessed by any cyanide solution, and this naturally improves adhesion. The composition of the cyanide bath is fairly elastic; we may have the type of solution known as a "striking" bath used as a cleaning and preliminary plating solution. It may contain one to two ounces copper cyanide, one to four ounces caustic soda and two to six ounces sodium cyanide per gallon. Operated at relatively high temperature—120° F., and at a current density of 15 to 40 amps. square feet for two to three minutes, large gas evolution occurs giving very effective cleaning

with a slow deposition of a film of copper. Considered purely as a plating bath, this would be too slow and a solution containing two to four ounces copper cyanide, two to four ounces sodium cyanide, and half ounce caustic soda per gallon is generally required. Operating conditions will vary according to the subsequent procedure—in the States it is common practice to operate the solution at about 120° F. and a current density of 20 amps. square feet for twenty to thirty minutes to give 0.0003 to 0.0005-in. deposit which is then buffed before nickel plating. Operating this cyanide copper bath at lower temperature and current density—such as around 10 amps. square feet for ten to twenty minutes will give a fine grained deposit of 0.0001 to 0.0002-in. thickness which may not require buffing.

The choice of the two procedures will depend upon the cost of cleaning which, of course, has to follow the copper buffing operation. With automatic cleaning equipment, the buffing of the thicker copper deposit is economical as it reduces the cost of the metal deposit, since less nickel is subsequently needed, and reduces overall polishing costs, as it permits shorter nickel buffing times. Where cleaning is not automatic and therefore is expensive, the thinner unbuffed copper deposit shows an overall economy.

The copper cyanide plating tank is a very simple affair—a plain mild steel tank with welded joints being quite safe. The practice sometimes followed on the continent of using an inner lead lining is, I think, quite an unnecessary expense. It is desirable that the work be continually moving in the solution during plating by mechanically causing the cathode bar to reciprocate, for in this way the grain size of the deposit, particularly at edges and high spots is reduced.

After the parts have been copper plated, they should be thoroughly swilled in cold water, dipped in five to ten per cent. H_2SO_4 solution, swilled and then nickel plated. I would like to mention here that it is good practice always to have current switched on to a vat before it is loaded, so that some current flows and deposition occurs immediately any article makes contact with the solution. To allow work to hang in a plating solution even for a very short time without any current flowing is running unnecessary risks of undesirable chemical reactions occurring on the work surface with resulting faulty adhesion troubles. Relatively recent English and European practice, which is particularly suitable for steel, is to omit copper plating and to use what is known as anodic sulphuric cleaning, followed by the deposition of nickel directly upon the steel. In this process, the work forms the anode in strong sulphuric acid in a strong lead-lined tank (12-lbs. lead) which lining forms the cathode or negative pole. Initially, a heavy current passes and oxygen is evolved fairly vigorously from the surface of the work, but very soon this surface becomes of a " passive " nature and the current drops to practically zero. The work surface has thus been very

completely cleaned and it has been claimed that it has become " degasified " to some extent, and the polish is destroyed—becoming of a matte finish due to marked and even etching attack. If the article is then thoroughly swilled in cold water and nickel plated, it is found that the nickel has a very high strength of adhesion to the steel. This is to a considerable extent due to the relatively " rough " and etched surface of the steel and as the surface characteristics of an electrodeposit are considerably determined by the surface characteristics of the base metal, the nickel surface is relatively " rough " and may require a 10 per cent. greater buffing time. A slightly heavier nickel deposit is necessary to meet these more severe buffing conditions. Other possible disadvantages of the process are the fact that it is not indiscriminately suitable for brass parts which may become badly stained and excessively deeply etched, also that it must be followed by thorough water swilling to prevent sulphuric acid being carried into the nickel plating solution and, also, strong sulphuric acid is not the nicest of solutions to be manipulated by possibly careless operators. The process will, however, eliminate scrap due to deposits peeling or stripping from steel base metal and it is thus being increasingly used.

Nickel Plating.

The next operation is nickel plating, and with the present day necessity of thick deposits and high production rates, what is known as the " Hot Single Salt " solution is the most suitable. This solution operating at not less than 95° F. and containing essentially 2½ lb. nickel sulphate per gallon can be used with current densities of from 20 to 100 amps. square foot, but a limiting condition to this speed factor is the property of throwing power which being a result of various factors previously mentioned, is found generally to vary *inversely* as the current density. Thus working at 100 amps. square feet will deposit a mean thickness of 0.001-in. in ten minutes, but due to the resulting poor throwing power, a part of intricate shape will be found to have relatively very thin deposits in the recesses, and very thick wasteful deposits on the high spots and edges. Operating at 20 amp. square foot will give very much less variation in deposit thickness and thus sound compromise for commercial practice is a current density of 25 to 35 amp. square feet, with a solution temperature of 100 to 140° F. It is also eminently desirable that a plating solution should have good conductivity, for while primarily it reduces power costs, it also gives more even current distribution over the cathode surface to reduce the tendency to excessive current density and the consequent coarse grained " burnt " deposits at sharp edges and corners, and it increases throwing power. Conductivity is increased by raising the solution temperature and also by adding to the solution what are known as "conducting salts"; for a nickel solu-

tion, these salts can be ammonium sulphate, magnesium sulphate, and sodium sulphate. Ammonium sulphate reduces the solubility of the nickel sulphate and increases the hardness of the deposited nickel. Magnesium sulphate is a completely safe salt to add up to eight ounces per gallon. Sodium sulphate is not commonly used apart from its presence up to 24 ounces per gallon in solutions specially used for deposition on zinc base castings. Other salts necessary to add to nickel plating solutions are those to facilitate the dissolving of the anodes ; in a plain solution of nickel sulphate, the pure nickel anodes become passive—that is, they do not dissolve in the solution as fast as the rate of flow of current demands, and they may even become completely insoluble and consequently nickel is deposited out of the solution on to the work at a greater rate than it is replaced in the solution from the anodes and the solution therefore becomes deficient in nickel and therefore slow in operation, and also develops an excess of free sulphuric acid. To maintain the correct dissolving rate of the anodes therefore, some soluble chloride salts must be present—nickel chloride in a concentration of 1½ to three ounces per gallon, is the most usual addition, although equivalent amounts of magnesium chloride or sodium chloride can be used instead. The properties of the deposited nickel are very largely determined by the amount of free sulphuric acid present—this used to be controlled by testing with litmus paper which should show the solution to be relatively acid by turning pink, also testing with congo red paper to which the solution should indicate alkalinity by turning it red. As these indicator papers change colour at different small degrees of acidity, their use defined the acidity of the solution within these small limits. Some more exact definition and control of acidity is necessary for subsequent chromium plating requirements and we now express this acidity in terms of hydrogen ion concentration denoted by the symbol pH. The free or active sulphuric acid in a solution is that acid which is dissociated into ions and thus the concentration of the hydrogen ions is the measure of the active sulphuric acid.

[The lecturer here explained on the blackboard the manner of derivation of the scale of pH.]

Nickel solutions should be controlled with limits of pH 5.6 to 5.9.

Increasing the active acidity to pH 5.0 gives a deposit that would tend to be hard and brittle, of bright appearance and probably " pitted " to some extent. A more alkaline solution of pH 6.6. or greater will cause the deposit to have a dark colour, to be brittle and flake off. Simple little testing sets are now cheaply available, such as the Capillator and suitable comparators, which enable the pH to be determined easily and cheaply, under ordinary workshop conditions and they should always be used. The more elaborate potentiometric estimation method is not at all suitable for shop use and should be confined to a laboratory.

The maintenance of this very small amount of active or ionised sulphuric acid in the solution will seem to be a difficult proposition, but it is simplified by the presence in the solution of what are known as " buffer " compounds—these are the salts of weak acids, and they have the effect of damping out or buffering changes of concentration of ionised acid which would normally occur when adding sulphuric acid to the solution. Boric acid is normally used for this purpose in a concentration of 1½ to four ounces per gallon, and it is thus possible to add a reasonable amount of sulphuric acid such as one fluid ounce to 100 gallons of plating solution without producing an undesirably large alteration of the hydrogen ion concentration. We can summarise all of these composition requirements as follows :

Nickel sulphate, 2½ lb. per gallon ; nickel chloride, two ounces per gallon ; boric acid, three ounces per gallon ; optional magnesium sulphate, three ounces per gallon ; operating temperature 100 to 140° F. ; current density 25 to 35 amps. square foot. This will deposit 0.001-in. in thirty to forty-five minutes.

With the use of this fairly rapid rate of working, it is necessary to prevent burning or excessive thickness and roughness of deposit on small delicate exposed sections and edges, by causing relative movement between the solution and the work. Thus agitating the solution by bubbling air through it, and reciprocating the cathode rod upon which the work is suspended are both very desirable. This high rate of deposition also demands that the solution shall be as free as possible from any sediment or suspended solid matter, for any such contamination settling on the work will cause a very marked roughness of the deposit, and subsequent polishing will probably pull these tiny rough nodules right out of the deposit, resulting in service failure due to porosity. Frequent and efficient filtration of the solution is therefore most necessary and it is desirable also to prevent contamination of the solutions from shopdust by the provision of cloth screens and hoods over the tanks. All anodes should be enclosed in bags to retain any fine solid matter resulting from their dissolving in the solution ; the anodes should of course, be as pure as possible and the rolled, depolarised, and electrolytic varieties are definitely preferable to the cast anodes.

A nickel plating tank may be of iron or wood and lined with 6 lb. chemical lead ; linings of hard and thick pitch have been used and in the States hard rubber linings are fairly common. This latter lining is the most efficient one since it is an insulator and prevents stray current losses due to " shorting " as from anodes through a lead-lining—a leadlining therefore must be insulated from the anodes by an inner lining of wood or wired glass. The rubber lining is not yet, I think, a successful proposition in this country.

It is important that during nickel plating, electrical contact should not be broken even for a short period of even seconds

duration, for the deposit may therefore consist of two layers of poor cohesion which will probably part company during subsequent chromium plating. A violently agitated solution may sometimes cause this double coating effect, if the work is not firmly supported, but with properly designed plating jigs which are justified on large production by their elimination of the cost and labour of wiring up, faulty contacts should not be possible. After nickel plating, the work should be swilled through cold water and then hot water to remove all nickel plating solution which can contaminate a subsequent chromium plating solution. The first cold water swill retains the bulk of the plating solution which can thus be returned to the plating tanks and the hot water gives fairly quick air drying, thus avoiding any need for sawdust.

The nickel deposit is then buffed using a fairly soft calico wheel with a surface speed around 8,000 feet per minute and applying a white finishing composition which consists of Vienna lime compounded with about 30 per cent. by weight of the usual grease base. In the States, with their rather higher wheel speeds, they keep their wheels very greasy by plentiful application of tallow grease, and the buffed surface has therefore to be cleaned, generally in an electrocleaner, followed by acid dip and water swill before chromium plating.

English practice keeps the buffing wheel relatively dry so that a simple hand wiping with a soft cloth and dry Vienna lime gives a condition of cleanliness that is adequate for chromium plating.

Chromium Plating.

Chromium was first electrolytically deposited by Bunsen in 1854 and various workers subsequently investigated the process without obtaining deposits that had any promise of useful commercial application. It was less than ten years ago that the possibility of consistently obtaining bright or lustrous deposits was realised, and the present really high standard of work produced has only been achieved as a result of an enormous amount of research work and patient effort in the plating shop. The prime cause of the difficulties is the very poor throwing power of the chromium plating solution and the fact that lustrous deposits are only obtained within a relatively narrow range of current density. Thus with a particular plating solution operating at 100 to 110° F., a current density of 50 amps. square foot, or less, will give no deposit of chromium at all; a current density of 80 amps. square foot—100 amps. square foot will give the required bright deposit and if the current density exceeds 130 to 140 amps. square foot, a grey matte or "burnt" deposit will result, and due to its great hardness, this is an expensive and often an impossible job to buff. Thus an article of irregular shape may have a "burnt" deposit on its high spots and edges, and yet have no chromium deposited at all in its recesses. Other

quite distinctive features of the process are the very high current density required and the low cathode efficiency. With average practice, the cathode efficiency will not be greatly in excess of 15 per cent.; that is, 85 per cent. of the current will not deposit chromium, but will merely generate hydrogen at the cathode. The chromium plating solution is highly poisonous and when carried up to some extent with this vigorously evolved gas, in the form of a fume, constitutes a real health hazard to the operation. A powerful exhaust system maintaining an air speed of 2,000 feet per minute across the tank must be fitted to all tanks to remove all of this fume. As the solution consists of a relatively strong solution of chromic acid in water and is very expensive, tanks must be carefully constructed to resist corrosion effects. In the early days, plain mild steel or Armco iron tanks were used, as the solution should be theoretically without action upon such material, but in practice, attack of the welded joints occurred and nowadays, mild steel tanks are lined with antimonial lead with burnt joints, and this lining is insulated from the anodes by wired glass sheets. Recently, tanks have been built with an outer water heating jacket and while this gives more gentle and even heating of inner tank, it is also a worthy insurance against the whole of the plating solution, worth some hundreds of pounds probably, slipping quietly down the drain during the night as a result of a sudden development of a leaky tank.

The original and common composition of the solution is $2\frac{1}{2}$-lbs. of chromic acid with about one-fifth fluid ounce of strong sulphuric acid added per gallon of water. This very small amount of sulphuric acid is all important for although it is not " consumed " or used up in any way during deposition, it has an essential catalytic action that controls the process, and in fact, in its absence no chromium is deposited at all. The total amount of sulphuric acid present in the solution should be in a constant relationship to the amount of chromic acid present and this ratio is generally taken as 1 : 100. under average conditions to give the best throwing power and widest plating range. Variation from this ratio reduces the plating range and thus causes lack of chromium deposited in recesses or more readily causes the deposit to be of the matte variety at edges and high spots. When making up this plating solution, it is necessary to know the amount of sulphuric acid that is present in the chromic acid itself as an impurity (usually it is not more than 0.15 per cent.), and this amount must be taken into account when calculating the amount of acid to be added to make up to the required 1 : 100 final ratio. Very low priced chromic acid will contain a relatively large amount of impurities and is therefore ultimately not cheap. This original formula for a plating solution is still widely used, particularly in the States and it is best operated at a temperature of 100

to 140° F., and a current density of 100 to 200 amps. square foot. A radiator shell may thus require a total current of 1,000 amps, and it is therefore necessary to support it from the cathode bar with solid copper strips or rod, to avoid excessive resistance and consequent over-heating of these supports. Good contacts to the work are similarly essential and as they must be quick acting to satisfy production times, these suspenders for chromium plating are expensive and call for a certain amount of ingenuity in their design. As no suitable insulating material has been evolved to withstand the action of the plating solution, the suspender surfaces cannot be insulated in any easy way and consequently chromium is constantly deposited on them. Unless care is taken in laying out the shape of the suspenders, we may find that where they contact with the parts to be plated, the latter may have a small area that is free from chromium due to the shielding action of the suspender. It is not surprising therefore, that efficient suspender design requires either extensive experience or the patient application of " trial and error " methods.

The production of intricately shaped parts evenly covered with a bright chromium deposit is only attained as a result of a rather highly developed operating technique. A first precaution is to chromium plate just as soon as possible after buffing the nickel ; a twenty-four hours old polished nickel surface cannot be so easily chromium plated as a freshly prepared surface. Secondly, with intricately shaped articles the practice of " striking " is common ; this consists of giving an abnormally high current for a short period at the commencement of plating and subsequently reducing down to the normal plating current. Thus, an article which would normally require a current corresponding to four volts across the tank would, immediately it is placed in the tank, have the voltage raised steadily to six for about ten to twenty seconds and then gradually and regularly reduced to four volts for the rest of the plating time. If the current density is initially too low when plating, a brown stain forms on the nickel surface and a very high current would be necessary subsequently to destroy this and deposit chromium.

The function of " striking " is therefore to prevent the formation of this stain by immediately covering the nickel surface with some chromium.

The actual choice of voltage and therefore current density for any article is a matter of experience or trial and error, particularly with difficult shapes. Thus, if the current density is slightly too low, a bright deposit will be given to the high places of the article, but the recesses will be bare of chromium. On the other hand, a slightly too high current density, will give bright chromium in the recesses but a burnt deposit on the high spots. An intricately shaped article may exhibit both of these extreme conditions, and

although it is possible to choose a current rate that will avoid burning and rely upon subsequent hand "faking" with small anodes—sometimes known as "doctoring" for bare recesses, this can hardly be advocated for consistent production practice, and the alternative procedure of using a high current rate that will adequately deposit in the recesses should be adopted with special measures to prevent "burning" at edges. The current that causes the "burning" obviously comes from the nearest anode so that reducing the size of this anode or moving it farther away from the work will effect reduction of this current. While these adjustments of anode positions will be helpful, it may be necessary to adopt the further precaution of using what are known as "robbers." These are pieces of strip metal hung from the cathode bar close to those places being "burnt"; they consequently receive some of the excessive current at these places and when they are correctly dimensioned and placed, they will eliminate the "burnt" deposit from the work.

The evolution of hydrogen that accompanies the deposition of chromium is very vigorous and this rush of gas from a hole or crevice on the work, may so seriously agitate the solution locally that current distribution is disturbed to the extent that deposition may be prevented and local bare areas result. To overcome this "gassing" effect, it may be necessary to plug these holes, etc., with wood or rubber. The necessity for these special precautions will therefore indicate that the chromium plating process is anything but foolproof and that each differently shaped part requires individual consideration and possible special and particular manipulation, but provision of special suspenders and "robbers," etc., does enable the procedure to be standardised and thus is production possible.

The time of deposition can, of course, be varied to suit quality requirements, but some early American experiments showed that a deposit corresponding to 400 amp. minutes square foot current—that is, 100 amps. square foot for four minutes, or 200 amps. square foot for two minutes gave a deposit that had a minimum porosity and which did give some additional corrosion resistance. The actual thickness of chromium corresponding to these current conditions is c.0.000018-in. $\left(\frac{1}{50{,}000}\text{ins.}\right)$; a thinner deposit was found to contain fine round pores, while thicker deposits had numerous microscopic cracks. This thickness is, of course, terribly small, although it can be said to be adequate since practically all American automobile output conforms to it; the hardness of the chromium enables it to stand up to any abrasion requirements of service and the actual corrosion resistance is, of course, determined almost entirely by the character of the underlying nickel (and copper) deposits.

In England, with rather different plating conditions, a heavier

chromium deposit is given ; with some proprietary plating installations a more concentrated solution is used—up to 5-lb.-gallon of chromic acid with a slightly lower sulphuric acid ratio than 1 : 100. Such solutions operate at a rather lower current density of about 80 amps. square foot with a temperature of 104 to 110° F. and a plating time of about ten minutes. From my own experience, I would say that our English practice possesses a slightly, but definitely, better throwing power and is consequently rather easier to operate, but the longer processing time is an obvious disadvantage from output volume point of view.

Following the plating operation, a relatively elaborate series of swilling operations is generally worth while—a first swill in warm water removes and retains most of the plating solution that is dragged out with the work. This first swill tank is never washed out, but is used for making up evaporation losses of the plating solution and the " drag out " loss of this latter solution at the cost of c. 8/- gallon is thus recovered. The work is next swilled through a warm neutralizing solution consisting of about four ounces/gallon of soda ash and thus any small amounts of plating solution remaining in any pockets or crevices in the work are rendered very much less harmful. A swill through cold running water to remove adhering neutralizing solution followed by swilling in hot water to facilitate drying then completes operations. A quick buffing operation with a soft loose wheel and a green polishing compound will remove water marks and any traces of " burnt " deposit at edges and leave the surface polished and clean fit for assembly.

Troubles.

This description of plating procedure would not be complete without some remarks about " troubles and how to cure them." Scratches are, of course, on principle always caused by the plater although generally some assembly mechanic blessed with a screwdriver and two left hands is the obvious reason and the remedy is rarely difficult to find. The irregular occurrences of areas devoid of chromium as rendered more noticeable by vigorously breathing upon the cold plated part, require a careful and exact check of the operating conditions, temperature, and voltage, and the cleanliness and soundness of all contacts on suspenders and busbars. The condition of the anode surface should also be examined before the solution is blamed for the trouble. The anodes should have an even covering of a brown lead peroxide powder, and any yellowish deposit of lead chromate should be removed with a brush and pumice powder and the anode replaced in the tank and current passed through until the correct brown powder surface covering is formed. After a tank has been allowed to stand for some time, without working, a worthy plan is to hang some scrap metal in the

solution from the cathode bar and pass a vigorous current through for ten to fifteen minutes to form a thoroughly good and fresh film of the brown oxide on the anodes. In practice, it is found, very fortunately, that the solution does not quickly or erratically get out of condition. Chromic acid must be regularly added to maintain the strength of the solution and an amount of about 1½-lbs. per 100 gallons per week is generally sufficient. Initially the amount can be determined by the use of a hydrometer, but it is generally found as a result of prolonged working that the solution will gradually increase in gravity due to accumulating impurities. The maintenance of the correct concentration of sulphuric acid is important and this can be determined as required by means of either chemical analysis or by what is known as the bent cathode test, which is an actual plating test on a small scale using a special copper cathode bent to the shape of the letter " L " of standard dimensions. A series of plating tests are made on a small quantity of the solution under precisely the same conditions of temperature, current and spacing of electrodes and varying only the ratio of concentrations of sulphuric and chromic acids by additions of these acids, and noting the effects of these additions upon the " throwing power " as shown on the special cathode. The addition necessary to give the best throwing power is thus determined, and can be simply calculated for the larger volume of solution in the plating tank which can thus be *safely* brought to its best working condition. It may be found that the solution is suffering from too great an amount of sulphuric acid, although this generally only results from abnormal contamination ; an obvious remedy is to throw away a portion of the solution and remake up to volume with water and add chromic acid to the normal concentration. This is expensive and it is better business to first withdraw, say, a quarter of the plating solution into a separate iron tank, heat it up to close on boiling point and add slowly to it, with continual stirring, a solution of barium hydroxide in water in an amount equivalent to say one ounce per gallon of plating solution. After thorough stirring, some of the sulphuric acid will be precipitated as a sludge and this can be allowed to settle and the clear solution returned to the plating tank. Even with these periodic adjustments of the solution, it is well worth while to have the solution analysed fully at least once a year to prevent any risks of continued gradual contamination causing its ultimate ruin.

Another trouble is the flaking, peeling, and blistering of the deposit ; the film of bright chromium of the order of thickness which we are considering, invariably adheres perfectly to the underlying nickel and the fact that the chromium is deposited with high internal stresses will thus pull off the nickel where its adhesion to the base metal is imperfect. Generally, therefore, this trouble has its origin in imperfect chemical cleanliness of the base metal

prior to copper and nickel plating, and the checking of these cleaning operations and the composition of the cleaning and dipping solutions is the line of attack. The nickel deposit must also be of the required thickness ; a thin deposit will readily peel and flake. The peeling trouble may be aggravated by inherent high internal stress and brittleness of the nickel deposit itself and these features may result from a too low temperature or excessive alkalinity of the nickel solution. A minor form of this trouble, due to alkalinity, may be seen after chromium plating, in the form of numerous very fine cracks visible generally at high spots, corners, and edges. Blistering as distinct from peeling or flaking, may additionally be caused by the copper cyanide plating bath : an inadequate prior acid dip—or a too rapid deposition rate in relation to the temperature of the solution or a large excess of free cyanide may be responsible, particularly on steel parts. The normally required standard of quality of chromium plated steel parts is that they shall withstand a fifteen-hour saltspray test, and failure to meet this requirement is indicative of insufficient thickness of the nickel deposit or its porosity. The thickness is merely a matter of checking time, current, and temperature plating conditions if the solution is known to be of correct concentration, as may be sufficiently indicated by testing with a hydrometer, and also if the electrical conditions of the tank itself are correct, which means the checking of all connections on busbars and anode hooks and ensuring that the tank has its full area of good anode surface. Other conditions being correct, porosity of the nickel film can be cured by plenty of filtration of the solution to obtain its complete freedom from solid or suspended matter and sludge.

Stripping.

The removal or stripping of faulty deposits has, I am afraid, of necessity, received a certain amount of attention. For the removal of chromium, the purely chemical method of degreasing the part and immersing it in 50 per cent. hydrochloric acid solution can be used. This is fairly quick and simple procedure particularly if the solution can be heated to, say, 120° F. by a steam coil. A lead-lined tank is, of course, required, and the acid is relatively expensive, but if the operation is carefully performed, it is often possible to thoroughly swill the part, lightly buff the nickel surface and then chromium plate again successfully. The chromium may also be removed electrolytically by making it the anode in a solution of caustic soda or soda ash or alternatively in a solution of oxalic acid 1 lb./gallon. The treatment in caustic soda may, if too vigorously carried out, " pit " and spoil the nickel deposit, but the oxalic acid solution is safer in this respect, but it requires a high voltage across the tank and should be fed by a 12-volt generator set.

Nickel can only be really satisfactorily removed electrolytically by suspending the work as anode in a solution of sulphuric acid of specific gravity 1.50 to 1.55 and contained in a wooden tank lined with 12-lbs. chemical lead. Lead sheets are hung in to form the cathode and depending upon the size of article in relation to cathode dimensions, 0.001-in. nickel may be removed in ten to thirty minutes when current is supplied from a six-volt. generator. With use, the solution becomes slower in action and may cause " pitting " of the base metal, and to overcome this, glycerine can be added up to a concentration of three ounces/gallon.

Other Engineering Applications of Electroplating.

Chromium for Wear Resistance.

The production of thick deposits of chromium of the order of 0.001-in. to 0.010-in. for the purposes of resisting wear and abrasion has found useful application such as for plug gauges, etc., and general building up work, but with these relatively massive deposits, their intrinsic and great brittleness limits their scope. The chromium is deposited directly on to the steel surface which has been prepared by sand blasting or anodic etching and thorough cleaning. The current density is rather higher than for bright plating and the deposit has matte appearance and it is advisable to use specially shaped anodes and continuous movement of the work, preferably rotation, to minimise the building up and burning of the deposit at edges and corners. The 2½-lbs./gallon solution is, I think, the most suitable and a rate of working corresponding to 0.00025-in. to 0.0005-in. thickness per hour will be generally suitable. Parts to be treated should be preferably 0.00025-in. to 0.00075-in. undersize per side by grinding before plating and the subsequent chromium deposit carefully ground down to size. A Norton alundum wheel, 3860 -K running at 5,500 feet per minute has been recommended, using very light cuts, and lapping can be applied for very accurate finishing. With expensive tools, etc., this process will show economies, but it requires some considerable skill and attention for successful operation.

Cadmium and Corrosion.

It has been estimated that the ravages of corrosion represent a loss throughout the world £50,000,000 per annum, and our utter familiarity with the sight of red rust on iron and steel should not blind us to the fact that cadmium plating offers a very effective prevention of this waste, although business and political economy may greatly limit its application. It is a relatively simple and foolproof process and a deposition for twenty minutes at 12 to 15 amps. square foot in a still tank will regularly and easily give a forty-eight hours' saltspray test resistance. The solution is worked

cold and may be made up of six to eight ounces cadmium cyanide and eight ounces sodium cyanide and one to four ounces caustic soda per gallon, or alternatively four to five ounces cadmium oxide, ten to twelve ounces sodium cyanide, and one to two ounces caustic soda per gallon. The cadmium deposit is of matte whitish grey appearance and is rarely used as a polished finish as its extreme softness prevents the attainment of a really high lustre. The steel parts generally, therefore, have no polishing operations upon them, but are merely cleaned, swilled, dipped in hydrochloric or sulphuric acid solution, swilled and cadmium plated followed by swilling and washing in hot water and drying off. The strength of the acid dip may need to be varied with the conditions of the steel surface, but 10 per cent. should be sufficient, for its function is solely to prevent the blistering of cadmium deposit. If it is essential to impart some polish to the cadmium surface, a very gentle treatment with a soft mop and rouge, or with a fine brass wire scratch brush, using in each case plenty of water, should be given. The character of the cadmium film as deposited under the normal conditions can be improved with regard to its grain size and appearance by the presence of what are known as addition agents in the solution—dextrin is commonly used, and turkey red oil, a small amount of nickel cyanide, and even the lowly condensed milk have been advocated. All of these give a brighter, smoother, and more fine grained deposit, which, however, more or less inevitably, is more brittle and has a greater tendency to cracking, blistering and flaking ; such addition agents, therefore, should only be used in a very cautious manner and only when really necessary. This statement applies equally well to all plating solutions and the uses of colloidal substances such as glue and gelatine and various gums, and such substances as beta-naphthol, ethyl sulphuric acid, etc., are best dispensed with if consistent and reliable operation of copper and other plating solutions is desired, for their effects are extremely powerful and if used in excess, hard, brittle, and flaking deposits result and it is neither easy nor cheap to remove an excess of these " tonics " from a large volume of solution. I would say that the only use of addition agents for improving the brightness of deposits that have been sufficiently used and experienced as to be safe, are the addition of sodium thiosulphate to copper cyanide bath, cadmium sulphate or a cadmium anode in nickel baths and glue, peptone, or oil of cloves in lead solutions.

Reverting to cadmium plating, trouble may be experienced with the bath developing a high resistance, so that an abnormally high voltage is necessary to maintain the requisite amperage. This is due to insoluble compounds forming on the cadmium anodes and to prevent and remedy this an excess of sodium cyanide must be maintained in the solution and anodes should be removed from the

solution each night or when not operating. The use of a proportion of iron anodes and a very small quantity of mercury potassium cyanide in the solution can also be adopted if the cadmium anode trouble persists. If the deposit becomes of a powdery nature and dark grey colour, it is most probably an indication that the solution is deficient of cadmium cyanide and this or an equivalent salt should be added.

Zinc plating has some vogue for corrosion resistance purposes, the sulphate and also the cyanide baths being used and their general characteristics are somewhat similar to the corresponding copper solutions although the zinc sulphate bath requires a more delicate control of the acidity, and addition agents, for successful operation. Generally, I would say that cadmium plating is the preferable process for most corrosion resistance purposes despite its higher cost. It is, by the way, *not suitable for brass work.*

Copper as anti-carburizer.

Copper plating as a medium for preventing carburization of a surface during the casehardening process for steel parts, has some engineering application, although where it is practicable, I have a very definite preference for the procedure of leaving surplus metal to be machined off after carburizing, as being a more reliable method and only rarely of greater cost. For the copper plating method, the part must be cleaned, swilled, dipped in 10 per cent. sulphuric or hydrochloric acid solution, swilled, given a preparatory deposit of about 0.0001-in. thick of nickel or copper from a cyanide bath, swilled and then a heavy deposit from the copper sulphate bath made, operating at 30 amps. square foot ; a plating time of thirty minutes will give a thickness of 0.0008-in. copper which should be ample for fairly severe carburizing conditions. Thinner deposits have been advocated, but I think that a little extra money spent on a thicker deposit to reduce any risks of hard spots, which may quickly ruin some very expensive tools, is not bad business. It can be taken as a golden rule that deposits should always be planned to be of ample thickness, and economies in this direction only gradually effected as large scale service and production experience proves them to be completely safe.

In touching upon some of the principal plating processes of engineering interest and application to-night, there is one practical control feature which I think requires emphasis and further explanation. I have liberally used the term current density and it is necessary that this should be identified with the use of voltmeter and ammeter as commonly fitted to plating tanks. Obviously, if a current density of 20 amps. square foot is to be maintained, it is merely necessary to calculate the surface area, of the articles being plated, in square feet and multiply by 20 and pass the resulting

number of amperes through the tank. The variation of current density upon various parts of an intricate shape due to lack of throwing power, and the consideration of calculating the surface area of a bathroom tap or a motor car mascot brings a realization that the proposition is not as easy as it sounds and consequently a special testing instrument known as a current density meter should be always available. This is hung into the plating bath from the cathode bar during deposition and consists of a cathode of known surface area connected through an ammeter to the cathode bar. Thus if its area is half square foot and its ammeter registers 10 amps., we know that the current density operating in the solution is 20 amps. square foot. Periodically checking a tank in this way, when average loads of parts are being handled and at the same time noting the voltmeter readings, will soon give the information of the voltage required to maintain any required current density in that tank at that particular temperature. It must be remembered, however, that increasing the temperature of the solution will increase its conductivity and therefore the current density for any given voltage, and also that average values only are possible.

While I can only pretend to have briefly and simply described some phases of electro-deposition to-night, I have deliberately avoided a lot of advanced and sometimes debatable details in order to try to show that the principles of the process are reasonable and rational and that a simple understanding of the elements of electro-chemistry can bring shop practices down to a basis of figures and therefore permit us to quantitatively measure and control our variables and effects, so that it is possible to " line up " a plating shop with other production areas. Automatic equipment is, of course, the final expression of this, but where volume of output does not permit of its adoption, the present possible consistent production with less than one per cent. scrap from a hand-operated shop is a rather remarkable tribute to the progress achieved by the united efforts of all of the personal elements concerned during the last ten to twenty years.

Discussion.

MR. S. CARLTON-SMITH (Section President): It may seem strange to some, or at least it would have seemed strange some years ago, that a lecture on the electrodeposition of metals should be regarded as of such importance as to be given the prominence of being chosen to be placed amongst the other important subjects of production engineering at our sessional meetings. The fact is that we were asked from several quarters to include this subject amongst our lectures. It is also a fact that there is hardly a production engineer to-day who is not concerned in his production with plating or deposition of metal to preserve or ornament articles which he is daily producing.

The splendid attendance we have here to-night confirms the interest which is evinced by production engineers in this subject. It is a further gratification to our section that we have in Luton an expert like Mr. Bavister to give us this lecture at Luton, Bedford, and District Section without being obliged to go further afield for the knowledge that he is able to impart to us.

Polishing is important, and cleanliness appears to be one of the greatest things. The throwing power of a solution is another factor that deserves close study. I should like to ask the lecturer how far experiments have gone in dealing with pieces of uneven shape where you get different thicknesses of deposit. Have you tried shaping the anodes to suit the uneven shape of the parts to be plated, instead of using "robbers"?

MR. BAVISTER: The special shaping and arranging of the anodes is possible and actually practiced to some extent, but for the economical production and marketing of anodes, they are generally made to standard plane sizes. With continuous plating production of any one article a standard layout of specially shaped anodes is practicable, but with a variety of shapes to be plated, the adoption of this practice alone, would entail carrying a large stock of special anodes and the labour associated with their frequent changing for different parts would be not inconsiderable. The alternative method of standardising a best compromise shape and distribution of anodes for all parts together with the use of "robbers" to avoid the "burning" of edges and corners of any extreme shapes is a much easier method for the operator and in general practice is found to be adequate.

MR. GREGORY: Can you tell us more about the comparative merits of different kinds of plating when exposed to atmosphere and corrosive liquids? There was no mention of plated parts submerged in water. Take the case of plated parts that are sometimes sub-

merged in mine water. Mine water frequently has a chemical reaction and attacks the plated parts; this is due to the water containing slightly acidic ferrous salts in solution. I have tested a considerable amount of chromium plating and in my opinion it is superior to cadmium. But there is the question of the materials on which the plating is deposited and whether they are machined parts or castings or forgings. It is realised that cadmium is a much softer material than chromium, and on castings, when immersed or when subjected to slight abrasive wear, it is more readily detached than is chromium.

In the case of immersion in an ammonia bath, in which non-ferrous castings like brass and gun metal are plated with cadmium or chromium, a good test for porosity of the platings is to immerse in an ammonia bath. Whereas a salt spray test may be satisfactory and show non-porous plating, immersed in an ammonia solution no cadmium is left. Chromium is not affected by the ammonia but due to the porous nature of the plating the ammonia passes through the pores to the base metal and may then cause flaking of the chromium plate.

MR. BAVISTER: With regard to Mr. Gregory's query I am afraid that I cannot be very helpful. It relates to resistance to corrosion, and exceedingly difficult matter upon which to attempt to generalise or standardise. As for the usual salt spray test, it is affective as a test for ferrous metal that has been plated to withstand normal atmospheric exposure. Beyond that I would say that its use is limited and qualified and to meet Mr. Gregory's conditions of total immersion in acidic ferrous solutions and also in ammoniacal solutions, I would not advocate its use.

MR. GREGORY: Then a salt spray test is of no use?

MR. BAVISTER: For your total immersion conditions with your special corroding agents, I would not use the salt spray test until I had definite experimental proof that its results were a valid indication of service behaviour.

Mr. Gregory describes corrosion conditions that are very different from what we usually get on the external parts of motor cars. A salt spray test is quite usual and effective in this connection. For total immersion conditions in ammoniacal solution, chromium would, I imagine, be about the most successful thing to use.

MR. GREGORY: Is nickel deposit less porous than chromium deposit?

MR. BAVISTER: Yes, a thick nickel deposit first and a chromium deposit subsequently should be more successful still, but, of course, the double process is more complicated and expensive.

MR. BEDFORD: I very much appreciate Mr. Bavister's lecture. Like an egg, it is full of meat. There are one or two things I should like to ask. First of all, I should like to know of any English

untarnishable cadmium plating. I believe that some process has recently been developed, and that it is claimed that it is untarnishable. Moreover, it is cheap. The Fescol process, I believe, depends for its success on the method and thickness of the deposit, and that it is not liable to flake off, like heavy coats of nickel deposited in the ordinary way. For some purposes it is an advantage to adopt the Fescol process.

MR. BAVISTER: I have no knowledge of any established English process of plating untarnishable cadmium although the technique of deposition of cadmium-silver-alloys of good tarnish resistance is receiving attention. Such alloys, however, are not cheap!

The brightness and lustre of cadmium deposits has been improved in recent years, but to my knowledge, tarnish and stain are always prone to development unless the surface is finally treated with a film of oil, soap or lacquer. With regard to thickness of the deposits in the Fescol process, this is certainly greater than that of normal practice, and the building up of these thick deposits requires a most careful and skilful control of all deposition conditions. The particular feature of the process is the great strength of adhesion of the deposits to the base metal and this is due in some degree, I believe, to the application of a variety of the anodic sulphuric etching process.

MR. GREGORY: Can chromium metal be deposited by the Fescol process? What is the difference in the hardness number compared with nickel, and does the hardness of plating depend upon the velocity with which the deposit is thrown?

MR. BAVISTER: Chromium is successfully deposited by the "Fescol" process. The hardness figure for nickel depends upon the plating conditions and the composition of the solutions used. Commonly, the Brinell hardness for nickel is in the neighbourhood of Brinell number 250, whereas that for chromium is probably about number 900.

MR. S. GILBERT: May we look forward to the possibility of electro-depositing tungsten carbide onto mild steel as a process for improving and cheapening our cutting tools?

MR. BAVISTER: There are few things to which one likes to say "No," but the possibility of this is rather contrary to the known laws and theories of electro-deposition, for the reason that it appears inevitably to involve the solubility of such a compound in a usable plating solution and tungsten carbide, like most other carbides and most very hard materials, is insoluble.

MR. GILBERT: I should like to draw attention to an economic aspect of electroplating which it appears to me is almost entirely neglected, and that is the relative cost of heating of tanks by different methods. Taking standard costs of coal, of gas, and of electricity, the comparative costs have been worked out as follows: steam, 1d.; gas, 6d.; electricity, 1s. 2d. This rather surprising

comparison is worked out moreover with electricity as low as ½d. per unit.

MR. BAVISTER: With regard to method and cost of heating, I admit there are very few published data easily available but there are often several considerations other than cost to be reckoned with in determining which fuel shall be used. Gas is nearly universally available but is generally very inefficiently applied and therefore costly. Heating by electricity is generally slow but thermally efficient, but I am surprised to note that you found it to be dearer than gas. Some figures which I have, show the cost ratios for heating tanks by steam, gas, and electricity, to be 1 : 8 : 2. As far as cost and general suitability are concerned, I would say that the steam coil is the best method although the cost will depend upon the size, and therefore "overheads," of the actual steam raising plant.

COMMANDER MATRAVERS: I would like to add my admiration for the really masterly way in which Mr. Bavister has dealt with a very difficult subject. It is quite impossible to take all of it in, but I shall certainly make a point of getting a copy of it. There are two points that I would like to mention. The first is: I thought there were two types of chromium plating, one soft and one very hard. [He mentioned about scratching a radiator.]

The chromium plating used for plug gauges you cannot scratch, Brinell number is, I imagine, 900. Can you give me any information regarding differences of hardness and, if any, how they are obtained? My second point is in regard to the question of adhesion of chromium to nickel and secondly direct on steel. I believe the method by which plug gauges are brought up to the given size, is a method of plating direct on steel and presumably, the adhesion between the one and the other is of a very high order. With chromium plated gauges, in the modern approved manner, the life is nine times that of the original hardened steel gauge unplated. If they stand up in this manner the cohesion must be very good indeed. It is extraordinary that in face of all difficulties in chromium plating, you get results like the success that is obtained in small shops.

MR. BAVISTER: I do not think there are two varieties of chromium which can be designated as soft and hard. I think the majority of deposits, in the bright chromium range are of the same hardness. The question hinges upon a definition of hardness—a difficult matter! Actually our conception of hardness involves some realisation of resistance to penetration or deformation and when considering the usual film of bright chromium of c. 0.00002-in. thickness, it is almost impossible to isolate or determine that it has any such concrete mechanical properties. The properties of such a film upon copper could not, for instance, under normal testing procedure,

be differentiated from the properties of the copper as regards strength and hardness. The hardness of a thick chromium deposit can, of course, be tested and realised. Hence, I think has arisen the idea of soft and hard chromium ; the usual plating solutions, operated normally, give deposits of similar hardness. As regards adhesion on plug gauges, one necessity is very careful cleaning and some etching or roughening of the base metal surface so as to get the chromium deposit interlocking sufficiently with the surface of that base metal. If you drop a chromium plated plug gauge onto a concrete floor you will find that it is not so robust as you would wish. Chromium is intrinsically brittle and it does not withstand shock or rough usage. Referring to the quality of work got out of small shops, I agree that it is really a high tribute to their personnel. It shows, however, that to accomplish anything, commonsense and hard work can be applied by *anybody* and will result in real achievement. Research and theoretical work are originally necessary to shape or direct any development efforts, but having obtained the purely scientific facts and knowledge, a tremendous amount of hard work and application is invariably necessary to achieve commercial and production success to the end of earning money.

MR. LEE : Can you tell me why the conductivity of a solution goes up with a rise in temperature ? Secondly, why is not oil fuel more in favour on the question of cost ? For 20,000 thermal units of gas, at a price of 8d. per therm, you pay 1.6 pence against a cost of 1d. for paraffin at a price of 8d. per gallon.

MR. BAVISTER : The increase of conductivity with an increase in temperature is due to the fact that current is transported through the solution entirely by the ions which increase in mobility, or speed of movement, due to the reduced viscosity of the solution as the temperature is increased. At the same time, the actual number of ions decreases but this effect is smaller than that of the increased ionic mobility. As regards the question of heating, comparing gas with oil, oil is definitely the cheaper fuel, but it does not admit of quite such easy temperature control and it is not as clean in general use and, of course, on principle, any plater just keeps all traces of oil or grease as far away from plating solutions as possible.

MR. JENKINS : Would it not be as well for Mr. Bavister to give some warning as to the dangers attendant on chromium plating processes. In spite of Board of Trade regulations many people are unaware of these dangers and solutions are handled unscientifically. As a consequence, ulceration occurs on various parts of the operator's body. The use of vaseline or lanoline is a preventative and the use of a neutralizing medium such as a five per cent. solution of sodium bisulphite is beneficial.

MR. BAVISTER : In the early days of chromium plating as a works process, it had some serious dangers to health. Board of Trade

regulations are now quite comprehensive and the compulsory fitting of efficient exhausting equipment to look after the "fumes" and the wearing of rubber boots, aprons and gloves by the operators and regular medical inspections have, I think, removed most of the serious risks. Vaseline or lanoline are effective and can be lavishly used for internal nasal application and the sodium bisulphite is about the safest neutralizing solution that can be applied to skin wounds. It is desirable, however, that these latter should receive proper medical attention and dressing, as chromium ulceration is far more easily prevented than cured.

MR. PUDGE: In the matter of polishing the articles, is not the difficulty that of not being able to run polishing spindles at sufficiently high speeds?

MR. BAVISTER: Peripheral wheel speed determines the rate of polishing, hence, a higher spindle speed reduces polishing time. The limit to this is a matter of lathe bearing design and also a question of the wheel "cutting" cleanly without burnishing or tearing. In U.S.A. a tallow grease lubricant is commonly used on the wheel, and this facilitates high wheel speeds. Increased wheel speed, assuming a constant pressure on work on wheel, requires obviously greater power to drive. The development of polishing lathes has gone further in the States than it has here, and 6-h.p. and 7-h.p. lathes operating at 8,000 to 9,000 feet per minute are common and often standardised in a plant. From my experience, high duty polishing lathes cost far too much money. They are generally somewhat specially built and have small sales volume and this, I suppose, accounts largely for their high price.

MR. CARRIER: Referring to the question of anodic sulphuric cleaning of steel, I should like to know if any trouble was caused by any selective action of the etching. The acid attacks soft steel much more quickly than hard steel. One would presume, therefore, that a hardening steel containing soft spots on the surface would be unevenly etched. Is it necessary to de-grease the steel before anodic etching?

MR. BAVISTER: I have never met with uneven etching due probably entirely to the fact that parts treated have been of commercially uniform hardness. I certainly agree that soft spots in hardened steels would be indicated by their different etching rate. Although the process is not particularly sensitive to grease in traces, I would certainly advocate a prior degreasing operation on volume work.

MR. THOMAS: Referring to soft and hard chromium, I put it down to this: When chromium is deposited on gauges on hardened steel, etc., this gives the chromium a hard base and sufficient support so that the true hardness of the chromium can be tested by diamond or scleroscope. Referring to Commander Matravers'

question of scratching the radiator, where the chromium is deposited on to a soft base, such as copper, brass or unhardened steel, the thin deposit can be either punctured, depressed or fractured into the base metal, and you are actually testing the hardness of the base metal underneath the plating. One remark surprised me about chromium plating being done in shops : I was under the impression that, chromium had to be done in the open air, due to the fumes which are given off during chromium plating.

MR. BAVISTER : You are right in supposing that one can scratch through the chromium plating on, say, a radiator shell, as it is *very* thin, the object of so plating being solely for resistance to superficial tarnish. Chromium plating is perfectly safely carried out inside the shop. The Board of Trade stipulation of maintenance of efficient exhaust equipment quite completely eliminates any abnormal hazards from the fumes accompanying deposition.

MR. H. E. WEATHERLEY (Member of Council) : Referring to the Fescol treatment, I think that the main reason for the remarkable results obtained by the Fescol process is that a very high voltage is employed. At a Fescol plating works I visited, I noticed a voltmeter reading 6,000 volts.

MR. BAVISTER : I cannot imagine that a voltage of 6,000 has any direct application to the electro-deposition conditions. Do you know if this voltage had any connection to an apparatus for applying a high tension static discharge to chromium plated parts placed in a vacuum ?

MR. WEATHERLEY : Oh ! You must not ask me questions like that.—(Laughter).

MR. MILLS : May I inquire how " brass " plating is accomplished, as for many years the inherent difficulties could not be overcome, and in order to obtain similarity in colour, a process known as " close " plating was used, a solution was eventually evolved by, I believe, Messrs. Canning which solved the problem and resulted in considerable economy being effected.

MR. BAVISTER : Brass plating is a rather old art but a fairly complicated one. In essence, it is a combination of copper cyanide and zinc cyanide plating solutions, but the colour of the deposit—that is, its relative contents of copper and zinc—is affected by nearly all of the process variables. Alterations of temperature, of current density, of copper and zinc salt concentrations, of free cyanide and ammonia concentrations, of anode composition and corrosions, all and each will modify the colour of the deposit. Messrs. Canning certainly did a very useful work when they offered the requisite salts correctly mixed together, with relatively simple instructions for operating and maintenance. The value of a brass deposit is primarily a function of its colour and as this is so easily variable, the process requires considerable control attention and is therefore not so easy from a

production point of view. "Close plating" is, I believe, an old process involving soldering and was not electrolytic in its principle at all.

MR. SIDDALL: Referring to copper plating purely as a primary operation preparatory to chromium plating, can you tell me why you do not cadmium plate instead of a preliminary deposit of copper, in view of the highly satisfactory nature of cadmium plating as a resistant to corrosion?

MR. BAVISTER: While cadmium used alone has a successful resistance to corrosion, when in contact with copper or nickel, it does not reproduce this behaviour, and corrosion is in fact markedly accelerated. Also it is a very difficult and expensive metal to polish and this is of real importance when considered as an "undercoat" for chromium. In addition to it being thus inferior to copper, it is also a more expensive metal.

MR. PHILPOT: As regards copper and chromium plating, although preliminary copper plating is most desirable in the case of nickel plate, is it really advisable where chromium plating is concerned? We find that successful chromium plating depends on providing an electric plant of sufficient voltage and that an eight volt dynamo is necessary instead of the usual six volt. We find that this provision ensures success.

MR. BAVISTER: There is never any difficulty in chromium plating direct on copper but this combination is rarely used. To deposit copper prior to nickel for subsequent chromium plating is advantageous but not essential. A six volt set is usually useless for average chromium plating work, but plug gauges as large as two inches in diameter can be handled with a six volt set in a small tank. I would certainly advocate an eight volt set as a minimum. For large surfaces in a large tank, 12 volts are useful.

MR. GREGORY: Will chromium deposit direct on to aluminium castings.

MR. BAVISTER: Yes, this can be done, but it is not a very happy production process and the results are not as yet, reliably useful. The process requires special etching solutions, and very precise control is necessary.

MR. GREGORY: Do you find that you get a variation in the thickness of chromium deposit, and does this depend on the spacing of the plates and articles to be plated?

MR. BAVISTER: The thickness of deposit will vary in the same way as in any other plating process and depends on the position and shapes of the surfaces of the articles in relation to the anodes and upon the throwing power of the solution and the limited useful plating range.

MR. BROOMHEAD: I should like to pay my tribute to Mr. Bavister for this very interesting lecture which is of a highly technical nature.

Referring to chromium plating of plug and ring gauges, we have had 100 plug and ring gauges which showed wear amounting to .0005 to .001-in. built up to size again by chromium plating but they gave us little success as far as their subsequent life was concerned. Prior to that they had been in use eighteen months to two years. After chromium plating they only lasted up to size for about two months. In your own experience, is chromium plating of plug and ring gauges becoming a recognised fact ? You get the plate chipping off. Is this due to lying about ? The life of a chromium plated gauge is only eight per cent. of the life of a hardened steel gauge, unplated. Can you tell me if, to-day, chromium plating of gauges is worth while or not ?

MR. BAVISTER : Chromium plating of plug gauges is an accomplished fact and if really efficiently carried out, is economically worth while. I am very surprised to find that you experienced a reduced life and apparently due to wear. This is quite contrary to general experience. Inferior results from chromium plated gauges are in my experience, only due to " peeling " or " flaking " of the chromium deposit. This may arise from two causes—poor adhesion and poor plating practice or rough and careless handling of a correctly plated job. If it can be assured that gauges will be handled in the shops with due care then I think that the process will prove to be able to save money.

MR. LARSSON : I have the experience that the life of chromium plated gauges, rightly used, is about six times that of unplated ones. In one singular case a plated gauge had a lifetime which was 20 times that of a similar gauge not plated. This is, however, quite an extreme case, and I am not able to explain why this gauge stood up so long. To obtain good results from chromium plated plug gauges it is essential that they are handled properly by operators. It will not do to try to force them into the bore at an angle, as the edge will then be chipped and the plating peel off. It is also necessary that the sharp edges should be removed on the gauges.

MR. S. CARLTON-SMITH proposed a vote of thanks to the lecturer.

MR. BAVISTER : I am pleased to have given you this lecture this evening and I trust that some of it has proved of interest or use.